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CAN MODERN SCIENCE HARMONIZE PHYSICS AND BIOLOGICAL PHENOMENA? *

BY

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The extent to which the scientific laws of the inanimate world may be made to embrace as particular cases the phenomena of the animal world has for long presented a problem of profound interest to the chemist, the physicist, and the biologist. We know of no instances in which the animate being violates the principles of mechanics, the principles of thermodynamics, or any of those other principles of natural philosophy in their control of the large scale phenomena amenable to our observation. If for the present I discard the claims of the devotees of occult phenomena, the table-turners, the spiritualistic mediums, and the like, I have to confess that I cannot cause myself to ascend into the air against the force of gravity by any but the ordinary means of levitation. If, having ascended, I fall, I do the same amount of damage to that which I hit as would any other conglomeration of chemicals similar to myself, but without the attribute of what is called life. No one has been able to use me as a means of getting around the law of conservation of energy. There is no

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food which I can eat which will enable me to do more mechanical work than is represented by the chemical transformation of the food consumed. Even though you treat me in a more subtle manner as a piece of mechanism participating in phenomena concerned with the transference of heat into work, phenomena whose laws are based upon less obvious foundations than are the laws of dynamics, even here I conform to the behavior of inanimate matter. You cannot use me as a medium which, while obeying the laws of conservation of energy, will transform heat into work more efficiently than would be permitted by the second law of thermodynamics.

In spite of such considerations as the foregoing, there exist differences between animate and inanimate things which are very striking at first glance. Stones do not get up and walk about as do dogs. They do not appear to reproduce themselves, so as to create an ever-increasing volume of their kind. It is important that we inquire how far these differences are really fundamental; and the scope of this inquiry is of a much more subtle character today than it was fifty years ago. In the era of mid-Victorian science, we could point to determinism as a characteristic feature of the inanimate world, and free will as the characteristic feature of the animate world. Today this distinction can no longer be as sharply drawn, for we have come to regard the behavior of the inanimate world as governed by laws which are non-deterministic in atomic processes and which assume, therefore, only an apparent deterministic form in the behavior of matter in bulk—a determinism controlled largely by the laws of averages. The deterministic consistency of matter in bulk is something like the deterministic consistency of a crowd or nation. If I take the New York telephone book and look up the name of Mr. John Erasmus Smith on, say, the twentieth page, and without further knowledge of him, proceed to tell you what he will do in any given circumstances, I shall probably be very far wrong. If I describe the beauty of his violin playing, and he happens not to play the violin at all, I shall commit a gross error. Yet, if I take all the names on a page of that telephone book, if I take a crowd, I shall be able to tell with some considerable accuracy how that crowd will react to certain influences. If the stock market goes down, the crowd will be

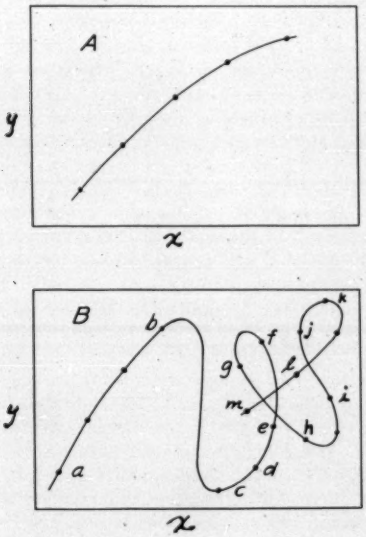
unhappy, in spite of the fact that Mr. John Erasmus Smith may be elated at this demonstration of the frailty of material wealth, or more probably of the fact that he hasn't any stocks. If there is disturbance somewhere in Europe, and I provide enough atrocity stories, the twentieth page of the New York telephone directory will want to go to war, in spite of the fact that Mr. John Erasmus Smith may have enough sense to weigh the history of other such propaganda in the past and want to keep out.

However, in spite of such considerations, it is not justifiable simply to say "Determinism is no longer the creed of the inanimate world and, therefore, the world of man and the world of stones are alike." In attempting to answer such a question as has been raised in the title of this paper, it is perhaps well to ask how far the question has meaning, and to attempt to define the sense in which it can have meaning.

In the first place, we must realize that it is always possible to take any aggregate of phenomena and harmonize them under some general scheme of law of which they form a part. The situation is rather analogous to the fact that if I plot a number of disconnected points, I can always draw a smooth curve which will pass through all of them, and a mathematician will be able to find for me a nice algebraical expression to represent the equation of this curve. If the points are distributed as in Fig. 1*A*, the mathematician will calculate y as a function of x so as to correspond to some such smooth curve as that drawn. I shall probably feel satisfied with this curve, and it will be a great help to me in harmonizing the relations of the points one to another and in enabling me to make calculations about them. If, however, the points are distributed as in Fig. 1*B*, while the mathematician will still be able to find a smooth curve which will pass through all of them, as shown in the figure, that curve will have entirely different characteristics in different parts. By contemplating the points lying between a and b, I shall get no concept of the kind of thing that is happening in the region c, d, e, f, g, etc. Of course, I could ask the mathematician to draw two distinct curves for me, one covering one region and the other covering the other. I could say that the points in these two regions have no connection whatever with each other. I work with the two re-

gions separately and get on very well and contentedly. If, however, I have the mathematician construct a continuous curve for all the points, I secure a sort of mental satisfaction in the harmonization so symbolized, but I must emphasize again to myself that the practical fruits of this harmonization are small. I can, as a matter of principle, say that the points

FIG. 1.



in the region *ab* are like the points in the region *c*, *d*, *e*, *f*, *g*, *h*, *i*, *j*, *k*, *l*, *m*, in that both sets form part of one continuous curve, but that the degree of a "likeness" does not carry much practical value.

The argument which I have made with regard to the points and the curves joining them is, as I have already remarked, only an analogy to the domain of facts versus theory, but it, nevertheless, serves to illustrate a feature of this domain which

we sometimes overlook. We must not fall into the temptation to feel that a theory which embraces all phenomena contains the richest story as regards those phenomena. The fact is that the more general it is the less it says, until in the limit when it is infinitely general it may say very little.

Some of the elements pertinent to a discussion of this kind may be brought out by considering the case of a physicist who studies the sciences of electricity and of gravitation separately and later comes to mould them into a common theory. It will be unnecessary for us to think of gravitation in the light of the general theory of relativity. The old Newtonian concept will suffice.

Our physicist studies the laws of the heavens and he finds that they conform very well to the Newtonian law of gravitation. I point out to him that some of the celestial bodies at any rate are magnets and that their attractions for one another will be modified in form and degree by this circumstance. The physicist replies quite correctly that the phenomenon is of very small numerical magnitude and that he proposes to neglect it. Next day, I find the physicist in his laboratory studying the attractions of magnets and of electrically charged bodies for one another. I point out to him that these bodies also attract gravitationally, and that he should take that into account. Again, he replies quite correctly that in these experiments the gravitational effects are so small compared with the electromagnetic effects that he is justified in neglecting them. In other words, in one problem of the universe he neglects the phenomena which are the whole source of interest in another problem, in which other problem, moreover, the phenomena dominant in the first problem are now negligible.

Now neglect of the small gravitational effect in the electromagnetic experiments is justifiable so long as one maintains the principle that the gravitational effect is, in actuality, there. If the gravitational effect is omitted, even in the principles of the subject, on the basis of its being too small to detect in these experiments, and if the laws of these experiments are, therefore, placed on the statute book without it, they will possess no power to recognize it in any other phenomena of nature where the circumstances may be different. They will, in fact, be in danger of actually denying its existence in any

field whatever and of rendering its subsequent discovery in the astronomical field a phenomenon puzzling to comprehend and apparently antagonistic to the science of electrodynamics.

Now, suppose a general theory embracing electrodynamics and gravitation is provided to take care of problems in which gravitational forces and electrodynamical forces are equally important even though nature may present us with no such cases of equal importance. Such a general theory is able to extrapolate itself at one end to a case where gravitation is unimportant and electrodynamics is all important, and to extrapolate itself also at the other end to a case where the relative importance of these respective phenomena is reversed. The theory thus provides a bridge by means of which the two extreme cases are seen to be not inharmonious, whereas individual theories for each case formulated on the basis of all that experiment can reveal would appear at first sight mutually antagonistic. The bridge having been provided, one need not force himself to meditate continually upon the problem in its full generality in all of its applications. When thinking of astronomy, one can think in his old way with no thought of electrodynamics; and when thinking of his laboratory experiments with magnets and the like, he can always think in his old way without meditating upon gravitation. He can invoke his philosophic bridge at any moment when his conscience begins to trouble him.

It is, of course, not surprising that nature should present in the form of different problems different phases of her activities, in some of which certain features are relatively inconspicuous, whereas they play the dominant rôle in other problems. Nevertheless, it is situations of this kind which are at the root of all philosophic difficulties which seem to make one branch of science inharmonious with another.

In cases where the problems presented by nature include a more or less continuous gradation of importance of different phenomena from one extreme to another, the mind becomes immediately content concerning the reconciliation of the extremes. When the problems presented do not have this characteristic of continuity of importance of the relative features, and when we are presented only with extremes, the reconciliation of those extremes involves an apparently greater

artificiality of theoretical coördination, and a greater responsibility for clarification rests upon a coördinating theory. The clarification tends to become enhanced by seeking particular cases of the theory which would, as it were, have a right to exist in nature and which would present the features of the theory in more equal importance.

Now in the fields of vital phenomena and of non-living matter, we are presented with a situation in which the extremes are emphasized, and in which we find no gradual transition from one extreme to the other. Nature does not present us with something which looks like a piece of copper, which can be used for building purposes, and which occasionally becomes irritated with the builder, or complains that its dinner is underdone. The bridge between the animate and the inanimate worlds is a rather narrow one. In crossing that bridge something which was absent on one side makes its appearance on the other, or perhaps we may hope to say that something which was inconspicuous on one side starts to assume a rôle of vital importance on the other.

The thing which is characteristic in living matter in its most elemental form is the power to reproduce itself in like kind. A single cell can divide and produce two which are alike, but the principle extends itself in more elaborate form to groups of cells, so that a single cell from a group can, by mere division, supplemented of course by feeding, produce a group of cells unlike itself for the most part, but like the group from which it originated. In other words, from a single cell can evolve a whole human being in such fashion that, if one of the parents from whom that single cell was formed had a bump on his nose, the bump will be transferred to the offspring, and again through subsequent generations to other offspring, possibly ad infinitum. The old physics presented little basis for understanding such a remarkable phenomenon. And yet I think we must admit that it did, in actuality, present cases of some resemblance. We are, of course, familiar in the atoms with forms existing in duplicate and, in fact, in multiplicate. There are many atoms of hydrogen; but until comparatively recently, at any rate, our belief was that the numbers of these various kinds of atoms in the universe could not change. In the molecules, however, we are familiar with

standard forms, whose numbers can be increased or decreased at will. We can actually destroy water as such, or we can create it. Going one stage further to a point at which we perhaps reach something more than an analogy with the vital case, we come to that of crystals, in which a group of molecules knows, as it were, how to arrange its individual members in such a manner as to realize in comparatively large size an entity, the crystal, with form and general physical properties determined ultimately by the characteristics of the molecules of which it is made. Only recently have we come to an approximation to a satisfactory understanding of the elements in our theories which are responsible for crystal structure. With these elements recognized, however, we have, I think, the germ of an understanding as to how a whole individual can be determined in form and characteristics from the single cell from which he originated. The crystal grows and perpetuates a form because the forces between the atoms provide not only for the structures of molecules but leave over a kind of remnant—an unsaturated remnant—characteristic of the group of molecules, which remnant controls the subsequent development of the group into the larger crystal form. In fact, the potentiality of that form, so different from that of the molecule itself, is contained, nevertheless, within the design of the molecule. The quantum theory of atomic structure, particularly in its wave-mechanical forms, has found a place for this residue of the main forces of the atom which is so powerful to control the structure of the groups of atoms. I have used the word "forces" as a convenience of language, although the mechanisms of the processes in the quantum theory are more easily understood in terms of laws of the ordering of things which do not deal with forces in the old mechanical sense. It is quite true that the method of development of the larger form in the case of the crystal is different from that in the case of the animal. Starting with that which we may regard as analogous to the germ cell, namely a crystal seed, that seed grows by taking to itself other molecules from the solution around it and building up the resulting crystal form, whereas the germ cell builds its structure by a process of division. However, processes analogous to cell division are not unknown in the atomic world. The ionization which oc-

curs when a salt dissolves in a liquid is a process in which a quantum state symbolic of the un-ionized molecule becomes unstable under changed environment. A whole cell may be thought of in a sense as a single quantum entity which can develop a condition of instability, either as a result of environment, or of internal development, so that division occurs, not, it is true, in an instantaneous act, but through the well known processes involving nuclear and chromosome divisions as intermediaries. The essential idea in this picture is that the original entity, having developed quantum instability, seeks a new stability in the form of two entities.

And so, such perpetuation of form as we find in crystal structure, and such development of instability as we find in processes of ionization, have forced a degree of generalization of view point in the inanimate world necessary to understand them; and this generalization paves, I think, the way for a better understanding of the more complex biological problem. It provides us with the hope that some day we may understand how what, again for the sake of convenience of language, I will call the residues of forces in the germ cells may possess the power to determine a large scale structure,[1] the completed being, with characteristics peculiar to the particular germ cell from which he originated as distinct from the general characteristics of a whole class of such beings, which characteristics may be supposed to be determined by the more obvious characteristics of the germ cell.

If we were to invoke such ideas simply for the understanding of vital processes, we might well be accused of simply inventing ad hoc a new set of principles, or a new concept such as vitalism, to explain the phenomenon of life, and this would relegate the phenomenon to a realm entirely divorced from laws pertaining to inanimate matter. The fact, however, that inanimate matter has taken upon itself for its own necessities the burden of enlarging the scope of that which is to be regarded as understandable in the behavior of physical phenomena, this fact adds prestige to the invocation of these concepts

[1] It is, of course, implied merely that the residues of forces in the germ cell determine, through cell division, the next order of complexity of structure whose force residues are characterized by the original cell, but which now in their own right determine the next stage of complexity, and so on.

in the vital field, even though in that field the complexities are at present so great as to prevent us from seeing, except through a hazy cloud of uncertainty, the successful, complete realization of their application. However, experiment, going hand in hand with theory, has helped to cement our confidence. Already physical experiments with the ultracentrifuge have led us to a knowledge of the existence of entities so small in form and simple in structure as to be understandable to the chemist and to the physicist as very large molecules—to be understandable as things brought into existence from inanimate matter by processes involving no elements of perplexity from the point of view of chemistry, but only elements of complexity. And yet, these structures, in good standing with the chemist as molecules, are almost of observable size, and show as a whole characteristics not dictated in any obvious manner from the elements which compose them, characteristics such as the power to promote cell division. According to the views above formulated, such a characteristic implies that the entity, by entering the cell, introduces an "internal environment" which renders the cell unstable in a manner crudely analogous to that in which the external environment of a solvent renders unstable a dissolved substance, thus causing it to become ionized. Moreover, these large molecules contain in their complexities of structure the power to promote what are presumably chemical changes in the things around them, chemical changes of a nature formerly very mysterious to the chemist and necessitating his invocation of mysterious processes and entities characterized by such terms as "catalytic action," "enzyme," and so forth. Even with the realization of the existence of these large molecules and of the evidence as to the nature of their actions, we do not yet clearly understand quite how those actions are produced; but their heritage is so clearly suggested in terms of what we do know, that we have every reason to believe that these problems are again problems of complexity rather than of perplexity.

In attempting to visualize a method by which a single cell, by the tortuous processes of successive determinations of form, realizes ultimately the characteristics of the complete individual, we may well be accused of far-fetched artificiality. Such appearance of artificiality is apt to be misleading, how-

ever, because it is apt to start out by viewing the phenomenon associated with what I have termed the residues of forces, as phenomena of an accidental kind without any order such as would provide for a powerful perpetuation of influence. The scenery, as viewed from what I have likened to the narrow bridge connecting vital with non-vital phenomena, is so unfamiliar to us that we hesitate to endow it with any responsibility. Yet, even physics in its most utilitarian aspects presents us with phenomena which must of necessity appear inexplicable, were it not that we have filled in the framework of understanding with a connecting bridge—a bridge which is satisfactory to us today, but would have been completely incomprehensible a century and a half ago.

I speak into a microphone and somebody hears my voice in Russia. We think we understand this very clearly because radio is so well developed. But think of what is happening in some of the wires in which flow currents concerned with the transmission of my speech through electrical transformation into what is heard as sound in Russia. The electrons which are responsible for those currents are moving in random direction with velocities of the order of a million centimeters per second. The kind of current that is associated with what has resulted from my voice involves a disturbance of the randomness of motion to such a small extent that on the average the velocities of the electrons are altered by only about one part in 10^{16} in favor of one direction. And yet, in order to perpetuate this speech with clarity, the alteration itself has to vary with time in a perfectly regular manner characterized by the nature of the sounds I am uttering. And if the tone of my voice heard in Russia is a little harsh in comparison with my natural voice, I shall grumble, so confident am I that the regularities should be able to perpetuate themselves through all the maze of irregularity with which they are intertwined. How is all this precise regularity perpetuated with such exactness in form through the comparatively infinitesimal disturbances of the motions of all the electrons in the transmitting apparatus? How, after faithful transmission across the oceans and continents is the story so exactly reproduced in the receiving apparatus? To the physicist who has studied these matters there is no great difficulty, but until he has ordered

the procedure concerned in detail, there was, or should have been, almost insuperable difficulty to anyone who thought about the matter. Great indeed would be the courage of him who would expect even the simplest form of telephone to work in an age before the details of the process were understood.

I have said as much as it seems expedient to say at this stage concerning such phenomena as the perpetuation of the characteristics of an individual through the intermediary of such a simple organism as a single cell. Let us now turn to the other great apparent difference between living and non-living matter, the difference concerned with determinism, free will, and the like. In seeking an answer to the question of how far such phenomena can be harmonized within the frame of modern science, it is important that we decide what kind of an answer we would be willing to accept for or against the success of such harmonization. What, in fact, would free will mean in science, and what would its absence mean?

The basic idea of a deterministic scheme of things such as characterized the science of the last century and of the early part of the present century is the idea that the sequence of events to happen in the future is controlled by laws which determine those events explicitly in terms of the *condition* of things at the present. However, the concept is to some extent ambiguous until we have defined explicitly what we mean by the condition of things at the present. To illustrate the matter, we may think of the heavens as governed by Newtonian astronomy. If I give the positions, velocities, and directions of motion of the bodies at the present instant, then the laws in question determine the subsequent history of their motions for all time. The assignment of positions, velocities, and directions constitutes what we must mean by the assignment of the *conditions of things at the present* in this scheme of laws.[2] If I give only the positions of the bodies, that is not enough. For the same assigned positions there is an infinite variety of subsequent histories of the bodies. If I state only

[2] Incidentally, any suspicion of *obviousness* of the determination of the future in terms of the present receives a severe shock by realization that, in terms of such laws as those here cited, the course of events from *now* to A.D. 10,000, for example, and indeed onwards, is equally well determined by the assignment of the conditions at that future date, A.D. 10,000.

the positions at the present time, and regard such specification as specification of the complete present, I am confronted with a kind of free will in the heavenly bodies; but stating the initial positions, velocities, and directions determines the subsequent history completely—*in Newtonian dynamics.*

On the other hand, it is easy to imagine another scheme of laws, different from those of the Newtonian scheme of gravitation, in which, to determine the subsequent history in terms of the present, we must specify not only the positions, velocities, and directions in that present, but other things as well.[3] To specify positions, velocities, and directions, and omit any one of these other things would be to leave the universe with a certain aspect of free will to him who erroneously thought the specification complete.

In the light of such considerations as the foregoing, the question of free will versus determinism may well be bound up with the degree to which we are willing to admit complexity in the specification of the present. The temptation to become beguiled from a deterministic view will become greater the more the nature of things is such that the things which specify the present divide themselves into two categories—the obvious things, and more subtle things which do not fuse themselves upon our consciousness.

However, the mind is apt to revolt against a completely deterministic view. At some moment I say to myself "I will point my finger to the east or to the west," but have not made up my mind as to which it shall be. I then make the decision to point west, and I do so. It is hard to say that the act of pointing west was preordained. However, it is hard, and even impossible, to prove that it was not. The complexity of conditions which have determined my previous life may have determined this act of pointing west as an inevitable consequence, a consequence which is hidden from me as such only because of the complexity of those conditions and the lack of immediate sensitivity of my senses to them.

Realizing the impossibility of denying a deterministic ex-

[3] The physicist will realize immediately that if the second order equations of the Newtonian theory are replaced by third order equations, for example, the specification of the present involves specification of positions, velocities, directions (of velocities) and also accelerations and directions of accelerations.

planation, but craving nevertheless an alternative, can we see on the horizon any alternative which can be regarded as consistent with the scheme of science as we know it today? We must be careful to avoid too easy a path of reconciliation by simply saying that the quantum theory of atomic phenomena is based upon statistical considerations, and has destroyed determinism so that free will and the like present no problems. For it is a characteristic feature of lack of determinism in quantum theory that such indeterminism shows itself for the most part only in connection with entities of atomic size, and the nature of the lack of determinism in the case of these entities is such as to smooth itself out, on the average, for the cases of matter in bulk, causing such matter to behave apparently in a consistent and deterministic manner. If I decrease the volume of a gas to one-half at constant temperature and find the pressure doubled on one occasion, I expect to find it doubled on all similar occasions. In view of such considerations, it is important to inquire whether we can cite any examples of cases where the chance nature of an *atomic* event may be seen to *determine* a chance characteristic in a phenomenon dealing with bodies of large size. I think we can give illustrations of such cases.

Thus, if I take a small quantity of radium, it will shoot out alpha particles with a "regular irregularity" based upon the laws of chance; and with well known detectors, we can actually observe these emissions of alpha particles. We can count the alpha particles one by one; and by suitable amplifying devices, we can cause the entry of an alpha particle into our detecting device to precipitate any large scale phenomenon we like to assign. We can cause a single alpha particle to initiate a process which will blow up a battleship. Suppose that, opposite our source of alpha particles, we place a screen with a hole in it, and suppose that our detector is connected to suitable apparatus designed to produce some large scale phenomenon which we shall call the phenomenon A. Suppose now that the detector is carried past the hole. It will be a matter of chance whether or not an alpha particle will pass through the hole as the detector passes by. If it does, the phenomenon A will happen. If it does not, the phenomenon will not happen. Nobody can predict in terms of the condi-

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tions existing before the detector is carried past the hole whether the phenomenon will or will not happen.[4]

Now, I do not wish to imply that the lack of predictability of events in the case of animate beings has anything to do with alpha particles passing through holes and entering detectors. I simply use the illustration to show that it is possible to realize conditions in which the lack of certainty of prediction of atomic events can be made to reflect itself in a lack of certainty in the prediction of large scale phenomena. It would be too involved a problem to attempt here the task of tracing this matter into the realm of biological mechanisms with the idea of realizing a plausible process by which the uncertainty of atomic phenomena may reflect an uncertainty in biological processes; and indeed, our knowledge of the details of what I have called the bridge which links the two is hardly developed enough to render such an attempt profitable at this time. I can do no more than express the view that the realization of such a mechanism does not seem an illogical dream.

It is worth while emphasizing one further point. If one is confronted with a situation in which it follows as a logical consequence of the "chance" nature of atomic laws that the actions of an individual are unpredictable, it is not logical to raise the further question as to whether the individual is responsible for his acts. To admit such a responsibility is simply to admit that the acts *are* controlled and then to throw oneself back to the nebulous discussion of how the individual makes his decision to control the acts and how he accomplishes that control. We cannot attempt a physical explanation and then run away from it directly we have it. On the views above cited, the happening of a certain unpredictable act is not the *result* of the choice of the individual, it *is* his choice.

The nebulous question as to whether the individual is to be held responsible for his acts is one which we can leave as finding its solution in the whole resulting scheme of things. It results as part of the said scheme of things that, on the average, if people do certain things, then certain other things happen to them as a consequence. The matter is summed

[4] Always, of course, supposing that in line with the spirit of the quantum theory, the atomic process itself is fundamentally indeterministic.

up [5] in the story of the slave whose master was a fatalist but, nevertheless, was in the act of beating his slave because he had lied to him. "But, Master," said the slave, "according to your own doctrine, it was preordained that I should tell you this lie, so why do you beat me?" "Ah," said the master, "it is true that it was preordained that you should lie, and the responsibility is not yours; but it was also preordained that I should beat you for it, and I am helpless to do otherwise."

And so there is no need even for the moralist to be unhappy about the matter. There is a logical place for him who endeavors to influence the wayward soul to better deeds, and thoughts. Let him not be depressed by the apparent inevitableness of it all or by the apparent dominance of chance in the discussion; for in the last analysis the whole scheme of laws by which man seeks to regulate his understanding of nature is but a pattern of his own creation which he imposes upon nature that he may in better fashion take her measure. Although, in one sense, man is the architect of his own thoughts, his thoughts themselves are part of the whole scheme of things; and to comprehend the relationship of things one to another, one must, as it were, himself step out of the picture, leaving his ghost to represent him therein. Then in the workings of what he sees, he will find man, with his mechanisms animate and inanimate. He will see the actions and reactions of all things one upon the other. He will see the mind of man, and indeed his own mind, all as part of the picture; and there need be nothing other than what it is in the picture. If it be thought that there should be aught else, let it be named, and the picture will reveal it somewhere as part of its own content.

[5] With the variation that the lack of responsibility of the slave in the story is based upon predetermination rather than chance.

HYPERFREQUENCY WAVES AND THEIR PRACTICAL USE.

BY

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1. WHAT DOES HYPERFREQUENCY MEAN?

The first question to be answered is concerned with the meaning of the word hyperfrequency. This has been commonly used for frequencies above 10^9 c/s. (1000 Mc/s.), which correspond to electromagnetic waves of wave-lengths shorter than 30 cm. What shall actually be studied in this paper is the behavior of electromagnetic waves whose wave-lengths are comprised between approximately one centimeter and a few decimeters. This region of the electromagnetic Spectrum holds for the moment a great deal of interest, due to many different reasons:

A. The physicist is especially anxious to study wave-lengths of the order of one centimeter and shorter. Very little is known of this region until one reaches wave-lengths of 0.1 mm. which correspond to the extreme infrared. Emission and absorption spectra are to be determined, together with optical properties of chemical compounds. Some very remarkable results have already been obtained, such as an absorption spectrum for ammonia and a strong change in the dielectric properties of water. These researches will become still more interesting when wave-lengths of a few millimeters or fractions of a millimeter can be produced with sufficient energy. It is to be foreseen that all chemical compounds having an electrical dipole should show a typical variation of their electrical properties in this region. These waves should enable us to build up new methods of investigations on molecular structures.

In a few words, the physicist is waiting for the gap to be filled between radio and optics; he still wants to link these two different fields together. This has already been tried

* Presented at a meeting held Thursday, April 6, 1939.

using damped waves, but precise measurements can be made only with continuous or undamped waves, and this is what we are now seeking.

B. The *radio engineer* is not less interested than the physicist. The tendency in radio has been, for the last twenty years, to push to shorter and shorter wave-lengths. Where is the practical limit to be found? No one to-day can tell; but it has already been demonstrated that wave-lengths of some centimeters may prove very valuable for radio communication, television, signalling (radio beacon), obstacle detection, not to forget dielectric cables. This is more than sufficient to arouse great interest and promote very active technical research.

2. SOME CHARACTERISTICS OF HYPERFREQUENCY WAVES.

Wave-lengths of some decimeters were first used by Hertz to repeat optical experiments, such as prismatic deflection or diffraction; and this *similarity of short radio-waves with optical waves* has been, since that time, emphasized by a great many experimenters. Optical lenses, mirrors, parabolic reflectors are very effective as soon as they can be built with dimensions of a few wave-lengths. Another and more recently discovered point is the *analogy between hyperfrequency radio-waves and acoustics*. Since the wave-lengths are of the same order of magnitude in both cases, we can now note the very important use of electrical apparatus curiously similar to acoustical instruments: hollow pipes, like organ pipes; hollow resonators (also called tank-resonators) reminiscent of Helmholtz acoustical resonators and dielectric cables, which show a marked relationship with pipes as used in acoustics.

Hollow tank resonators have been suggested by several physicists, mostly on the basis that they give very slight damping. As commonly expressed by radio engineers, these hollow resonators show very high Q factors: a high Q means that the resonator oscillates freely a great many times before the amplitude of the oscillations is reduced to a small value.

There is another aspect of the question which seems worth noticing; this is the possibility of first storing up energy in the resonator, and afterwards radiating this energy.

If one wishes to accumulate electromagnetic energy in a certain volume Φ, it can only be done by producing high electrical E and magnetic H fields inside this volume, the total energy being given by the integral

$$W = \frac{1}{8\pi}\int (\epsilon E^2 + \mu H^2) d\Phi. \tag{1}$$

The contributions of electrical and magnetic terms are usually of the same order of magnitude. But now there is one question to be raised, i.e. how far can we increase the fields? Let us suppose the dielectric medium to be air at atmospheric pressure. Its disruptive potential is about 30,000 volts per cm. that is 100 c.g.s. electrostatic units. Practically, this upper limit will never be reached, and taking a reasonable safety coefficient we may assume the average field to attain perhaps 15 E.S. units. This means

$$W = \frac{1}{8\pi}\overline{15^2} \approx 10 \text{ ergs per cubic cm.} \tag{2}$$

or 1 joule per cubic meter.

Thus we accept as a reasonable order of magnitude,

$$W \text{ (ergs)} = 10\Phi \text{ (cm.}^3\text{)}. \tag{3}$$

Storing up a large amount of energy W means using a resonator of large volume, Φ.

Now, let us think of the amount of energy radiated per second. A well tuned resonator will yield a Q factor of the order of 1,000, which means a time constant θ of about one thousand periods, τ.

$$\theta = 1000\tau. \tag{4}$$

The energy radiated per second $\frac{dW}{dt}$ is thus given by the relation

$$\frac{dW}{dt} = \frac{W}{\theta} = \frac{W}{1000\tau} = \frac{\Phi}{100\tau}, \tag{5}$$

using formula (3). Let us design a resonator able to radiate a power of 100 watts (10^9 erg/sec.). Its volume will be related

to the frequency by means of (5):

$$\frac{dW}{dt} = 10^9, \qquad \Phi = 10^{11}\,\tau. \qquad \text{C.G.S.}$$

This result may be more clearly understood if we compare the dimensions of the volume Φ to the wave-length λ. Supposing a cubic volume

$$\Phi = L^3$$

one finds

$$L^3 = 10^{11}\frac{\lambda}{c} = \frac{10}{3}\lambda, \qquad \text{C.G.S.}$$

where c represents the velocity of light, or

$$\left(\frac{L}{\lambda}\right)^3 = \frac{10}{3\lambda^2}, \qquad \lambda \text{ in cm.} \quad (6)$$

which yields the following results:

—long radio-waves, $\lambda \approx$ some meters,

$$\frac{L}{\lambda} \ll 1 \text{ lumped circuits;}$$

—short radio-waves, $\lambda \approx$ some decimeters, $\frac{L}{\lambda} \approx 1$;

—hyperfrequency waves, $\lambda \approx$ some cm. or some mm.,

$$\frac{L}{\lambda} \geqslant 1 \text{ tank circuits.}$$

For short radio-waves, ordinary inductance capacity circuits can no longer be used, and the technical practice is to use parallel lines or coaxial lines as resonators: however these lines can be built only if the distance between the two parallel wires is small with respect to the wave-length. This can no longer be obtained for hyperfrequency waves, and we are thus forced to work with tank resonators; even (due to $L > \lambda$) with tank resonators oscillating on their higher modes of vibration.

Other oscillators of great dimensions may be thought of, like conducting spheres or ellipsoids, these have been investigated in the early period of electromagnetism [1] and their resonance frequencies have been thoroughly computed, but their damping is far too high (Q factor very low) for practical use.

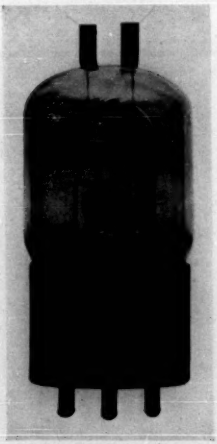
[1] M. Brillouin, "Propagation de l'Electricité," Hermann, Paris, 1904.

If rather similar to acoustical apparatus, a tank resonator is fundamentally very different, and the whole theory of hollow resonators, hollow tubes, etc., has to be built anew for the case of electromagnetics. The difference rests on the fact that acoustics deals with longitudinal waves, while electromagnetics deals with transversal waves. An acoustical field can be defined by one quantity (say the velocity potential) while an electromagnetic field needs four quantities (vector and scalar potentials). Acoustical calculations, as so marvellously done by Lord Rayleigh, may be used as a guide or as formal examples, but they have to be completely translated into the language of transversal waves and Maxwell's field equations, a translation which often needs a good deal of mathematical skill and ability.

3. FORMER EXPERIMENTS BY CLAVIER AND DARBORD.

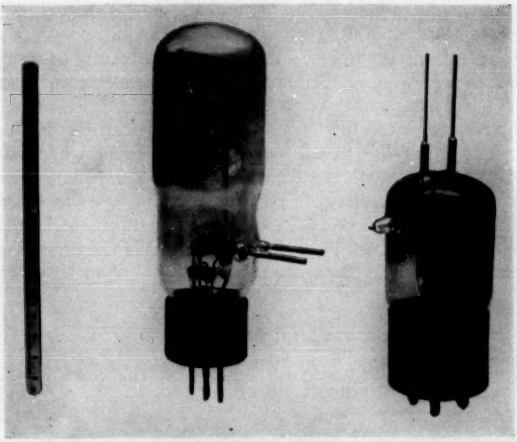
The "*Laboratoires L.M.T.*," laboratories of "Le Matériel Téléphonique" in Paris, have been very active for a good many

FIG. 1.



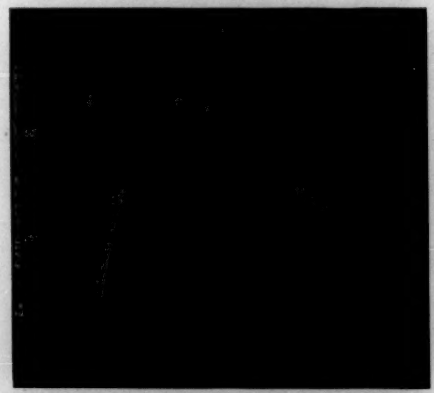
Microray oscillating tube (St. Inglevert).

FIG. 2.



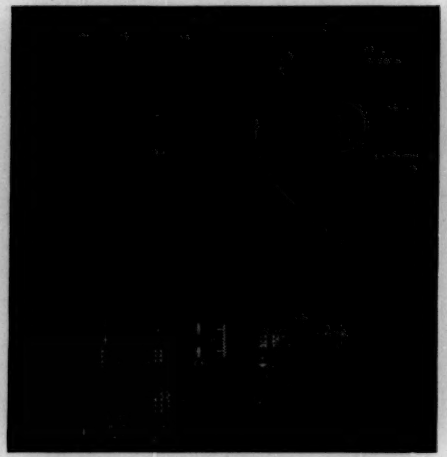
Microray tubes (St. Inglevert).

FIG. 3.



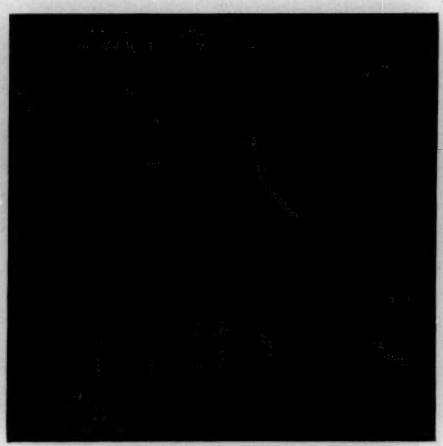
Relation of grid and anode potentials and variation of output for constant frequency. 19.4 cm. wave-length.

FIG. 4.



*P*2, demodulator potentiometer. *T*2, demodulator transformer. *A*2, 2-stage audiofrequency amplifier, max. gain 40 db. *TL*3, tubular transmission line to receiving aerial.

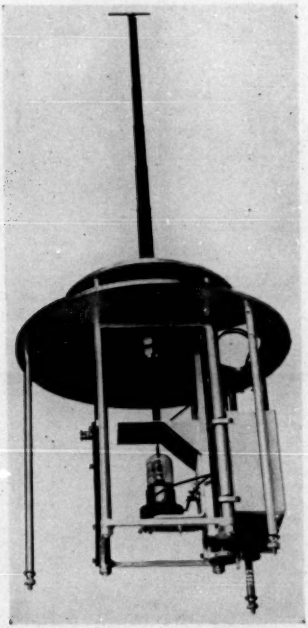
FIG. 5.



*P*1, modulation potentiometer. *T*1, modulation transformer. *A*1, 3-stage audiofrequency amplifier, max. gain 50 db. *TL*1, tubular transmission line to radiating aerial. *TL*2, tubular transmission line to thermocouple.

years in the field of hyperfrequencies. The researches were conducted by MM. Clavier, Darbord and various co-workers and have resulted in a radio transmission across the English Channel using a wave-length of 18 cm. The following pic-

FIG. 6.

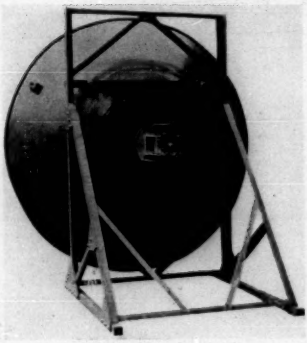


Mounting of oscillator or parabolic reflector.

tures give a good idea of this installation. First experiments were carried out in 1931 and the system has been in commercial use since 1934. The tubes used were of the positive grid type as shown in Figs. 1 and 2. Their characteristics are described in Fig. 3, the dotted line corresponding to anode

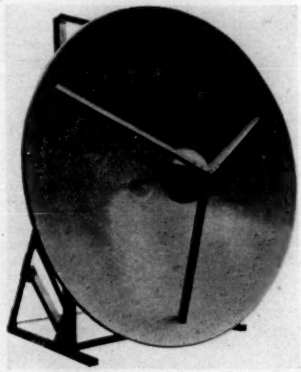
potential and the solid line to the output, both curves being plotted as functions of grid voltage. Figs. 4 and 5 show simplified schematics of the receiver (Fig. 4) and transmitter (Fig. 5); in both cases oscillations generated (or received) are conducted by a coaxial feeder to (or from) a small antenna disposed at the focus of a parabolic reflector. Details of this mounting may be seen in Fig. 6, which shows the oscillating tube and its feeder. Fig. 7 is a rear view of the reflector fitted with the preceding mounting, while Fig. 8 shows a front view of the

FIG. 7.



Reflector rear view.

FIG. 8.



Reflector front view.

same reflector together with a small hemispheric mirror reflecting waves back on to the parabolic system.

The reflectors produce a linear beam of very small aperture, directed from the transmitting station to the receiving station. The reflectors must be in direct sight. In the cross channel communications example, one of the stations is located at St. Inglevert on the French side, the other at Lympne in England, the distance being about 56 kilometers, and the sites so chosen that the line between the terminals is clear of obstacles. The electro-optical equipments are in-

stalled on suitable steel towers (20 meters high) shown on Fig. 9 (St. Inglevert) and Fig. 10 (Lympne). The link is used for two-way teleprinter messages as well as duplex telephony.

FIG. 9.

Microray towers at St. Inglevert (20 meters high).

V.2
194

All details about these stations have already been published in various papers.[2]

The results of operation were very good on this link, which represents the shortest wave-length circuit in commercial use.

FIG. 10.

Lympne terminal.

Atmospherics are never heard on the circuits, though sharp clicks, not to be traced to the apparatus, are sometimes noticed. No interference whatever is caused either by thun-

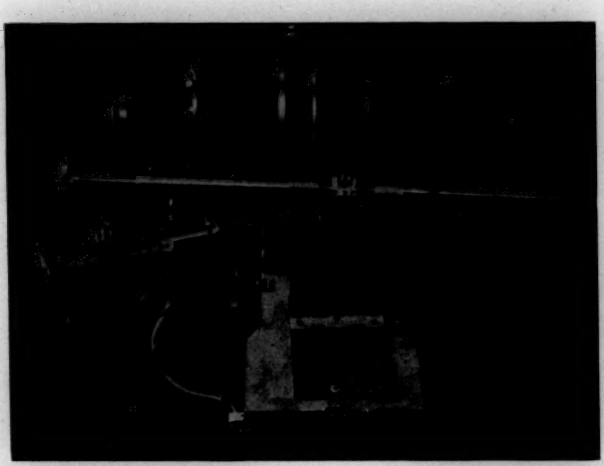
[2] A. G. Clavier, *Electrical Communication*, 1933, **12**: 3. A. G. Clavier, and L. C. Gallant, *El. Comm.*, 1934, **12**: 222. W. L. McPherson and E. H. Ullrich, *P. I. E. E.*, 1936—"The Institution of Electrical Engineers"—Proceedings of the Wireless Section, 1936, **11**: 253–291.

derstorms or motorcars; the background noise in the receiver exactly resembles normal tube noise. Some slow fading has been observed, although it very seldom occurs that for a short duration of time the signal is unreadable for telegraphy. Rain and fog show no marked effect. As a rule, stable atmospheric conditions, whatever they might be, corresponded to stable communications while unsteady atmospheric states are usually accompanied by fading.

4. DIELECTRIC CABLES: EXPERIMENTAL.

A very important step was taken when Southworth, Carson, Mead and Schelkunoff from the Bell Laboratories first

FIG. 11



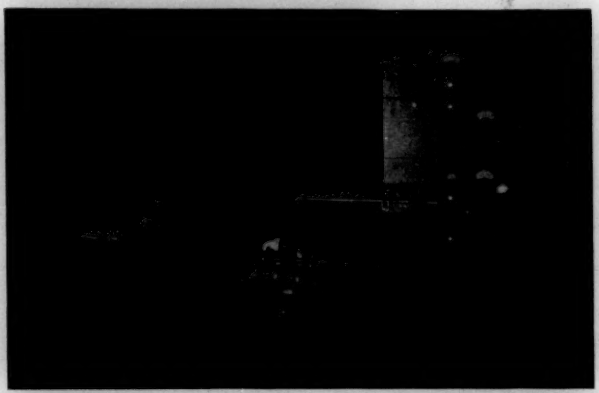
Clavier's magnetron. Photo showing the generator of oscillation at a wave-length of 2.5 cm. (in air) and its associated wave meter; also the method of coupling to a dielectric guide 1.6 cm. internal diameter.

began investigating short wave propagation along conducting hollow tubes (so-called dielectric cables). Very similar researches were started almost at the same time by Barrow at

FIG. 12.

Dielectric cable properties demonstration.

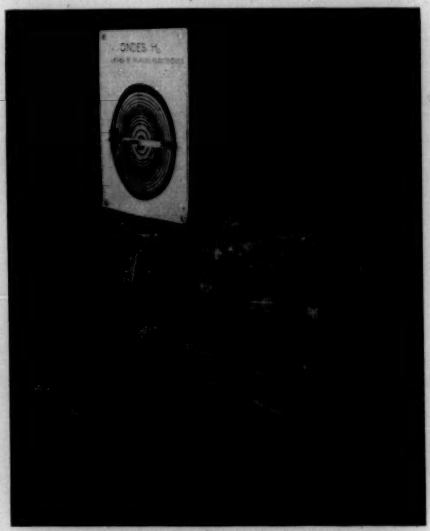
FIG. 13.



Hyperfrequency generator. Photo showing in the middle a generator (8 cm. wave-length) together with wave-meter. On the left the coupling apparatus to a dielectric guide 12 cm. in diameter. On the right-hand side the receiving apparatus of a dielectric guide 1.6 mm. inside diameter.

the Massachusetts Institute of Technology.[3] The first papers published by these scientists aroused the curiosity of many physicists. The author investigated wave propagation in rectangular tubes, then in tubes with elliptical cross section,[4]

FIG. 14.



Dielectric cable receiver. Photo showing the receiving side of a dielectric guide 12 cm. in diameter with means for demonstrating the distribution of electric lines of force for different types of waves.

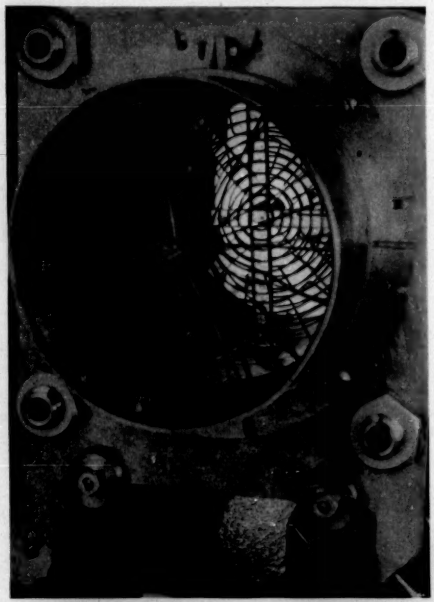
and a great many further studies have recently appeared. Researches conducted in the U. S. A. being already well known to the readers, it may be desirable to give more detailed information on the work done in Europe, and more particularly

[3] G. C. Southworth, *Bell System Technical Journal*, 1936, 15: 284. Carson, Mead and Schelkunoff, *Bell System Technical Journal*, 1936, 15: 310. W. L. Barrow, P. I. R. E., 1936, 24: 1298.

[4] L. Brillouin, *Revue Générale de l'Électricité*, 1936, 40: 227. *Electrical Communication*, 1938, 16: 390. *Bulletin Soc. Franç. Électriciens*, 1938, 8: 899.

on the researches of the author, in connection with A. G. Clavier [5] from the "Laboratoires L. M. T." in Paris. Mr. Clavier has presented very brilliant experimental demonstra-

FIG. 15.



Wave transformer. Photo showing the apparatus used to transform one type of wave into another (here E_0 wave into H_0 wave) and the associated filter to eliminate the unwanted remaining portion of the original wave (E_0). Transmission takes place back to front in the apparatus as shown.

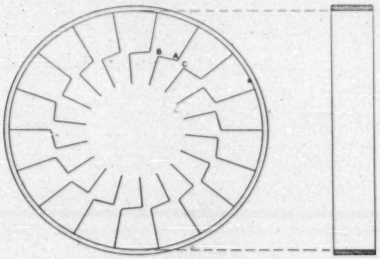
tions before the "Société Française de Physique" in November 1938 using the equipment shown in the following figures.

Very short waves were produced either with positive grid tubes of the type formerly described in this paper (Figs. 1, 2

[5] A. G. Clavier, *Bulletin Soc. Fr. Électriciens*, 1938, 8: 385. A. G. Clavier and V. Altovsky, *Rev. Gén. de l'Électricité*, 1939, 45: 697–731.

and 3) or with magnetrons. Fig. 11 is a view of a magnetron equipment generating waves of 1.2 to 3 cm. wave-lengths. These waves can be propagated inside a small copper tube 1.6 cm. in diameter. Near the magnetron is a coaxial line wave-meter having a moving piston for tuning. Fig. 12 shows a general view of the dielectric cable experiment as demonstrated before the French Physical Society. Two different guides were used; a large one, 12 cm. in diameter, is to be seen in the foreground of the picture and enabled Clavier to study before the audience the distribution of electrical lines of force inside the tube for different wave types. The smaller guide was the

FIG. 16.



Wave transformer design.

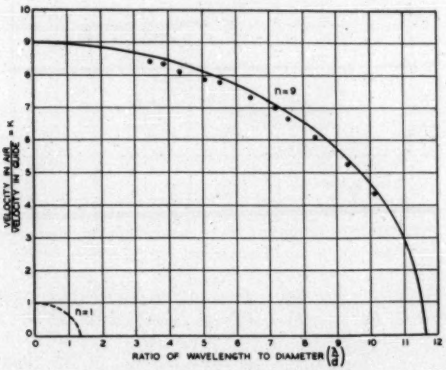
tube of 1.6 cm. diameter already described. Fig. 13 shows the generator (positive grid tube) for 8 cm. wave-length together with coaxial wave-meter. On the left is the coupling apparatus with the dielectric guide of 12 cm. diameter, with means for demonstrating the distribution of electrical lines of force for different types of waves. A small dipole antenna may be rotated inside the tube and received amplified signals are indicated by a small lamp which is correspondingly oriented with respect to an indicating placard. Figure 15 shows a transformer for changing the type of wave from E_0 to H_0. The transformer itself consists of small radial antenna inside the tube, having a bent portion at the radius where the H_0 wave has its maximum electrical field value. The antenna system is located between two screens, one with radial wires

stopping the E_0 wave but letting the H_0 wave through; the other screen (behind) is fitted with circular wires and stops the H_0 wave while the E_0 wave passes unperturbed. Figure 16 is a drawing of the antenna system of the preceding transformer. More detailed information in regard to this equipment may be found in the paper by Clavier and Altovsky quoted above.

5. THEORY OF DIELECTRIC CABLES.

A hollow conducting tube represents, for electromagnetic waves, an actual high-pass filter as only frequencies higher

FIG. 17.



Velocity ratio for E_0 type of wave in a metal pipe filled with an insulator.

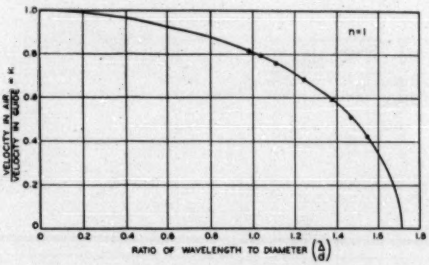
than a certain cut-off frequency can be transmitted through it. This result was one of the very striking facts from Southworth's first investigations, and may be readily seen from Fig. 17. The curve shows the variation of

$$\frac{W}{V} = \frac{U}{W} \tag{8}$$

as a function of the ratio λ/d of wave-length to diameter; W, light velocity in free space; V, phase velocity for guided waves

inside the tube and U, the group or signal velocity for the guided waves. The solid curve is the theoretical one for E_0 waves in a tube filled with water ($\epsilon = 81$, $\sqrt{\epsilon} = 9$). Only wave-lengths less than the cut-off wave-length can be propagated through the tube. Cut-off occurs here at $\lambda/d = 1.7$ approximately. Figure 18 shows a similar curve for H_1 waves in a tube filled with air, with cut-off about $\lambda/d = 1.67$. Physical interpretation of these results will be given further on. It is to be noticed that theoretical curves, on Figs. 17 and 18 are actual ellipses. Figure 19 is also from Southworth's

FIG. 18.



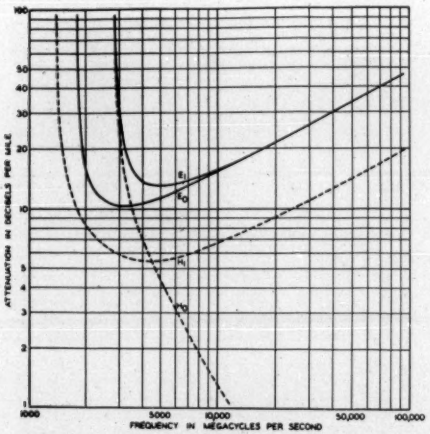
Velocity ratio for the H_1 type of wave in a hollow metal pipe.

paper and illustrates the attenuation for different types of waves (called E_0, E_1, H_0, H_1) as propagated along a copper tube. Very remarkable is the decreasing curve for H_0 waves; the higher the frequency the smaller the attenuation. This unexpected and rather surprising result might prove very valuable for long distance dielectric cable communications. When looking at this problem with more precision, such a result can be explained in a few words. Each type of wave induces electrical currents in the copper tube; these currents have to flow inside a very thin layer (due to skin effect) and this layer becomes thinner and thinner as the frequency increases. This results in increasing Joule's losses inside the layer for most types of waves. Hence the higher the frequency the greater the attenuation. H_0 waves behave differently, because the current intensity induced in the copper

tube decreases very rapidly as the frequency increases, and this second effect more than compensates for the decrease in current penetration depth. Thus the attenuation decreases as the frequency increases.

Let us now return to the elliptic curves of Figs. 17 and 18, and explain their physical meaning. The remarkable point is that the wave velocity inside the tubes differs substantially

FIG. 19.

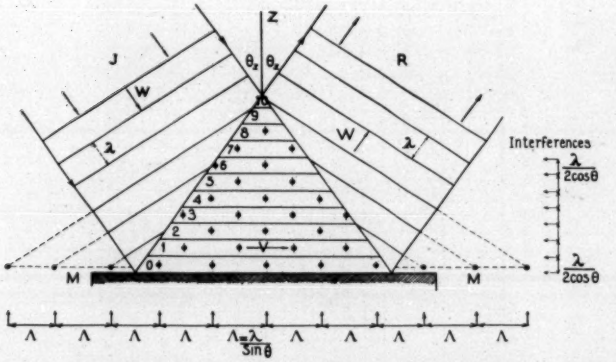


Attenuations suffered by each of the more common types of waves in a hollow copper pipe 5 inches in diameter.

from wave velocity in free space. What actually happens inside the conducting tube is that a system of moving interferences, a certain pattern of alternating maxima and minima, is built up inside the tube, and then moves as a whole, drifting along the tube without any distortion. It is readily understood that the phase velocity (or propagation velocity) for such an interference pattern will be very different from the usual light velocity in free space. Some elementary examples will give simple instances of such properties; Fig. 20 describes interferences actually taking place in front of a mirror M, when

an incident wave J falling at an angle θ is reflected, yielding a reflected wave R. There is an interference pattern in a triangular region in front of the mirror where incident and reflected waves superimpose. Intensity maxima, as indicated by dark dots are built up at the intersection of wave planes from both waves; λ being the wave-length of a free wave, there appears a longer wave-length Λ in the interference pattern, as representing the distance between two dots, measured parallel to the mirror. It should be noticed that the whole motion of

FIG. 20.



Reflection on a mirror M of an incoming wave J producing a reflected wave R.

this interference pattern occurs parallel to the mirror, the entire system gliding along with velocity V; this drawing immediately yields a very simple result:

$$\frac{W}{V} = \frac{\lambda}{\Lambda} = \sin\theta. \tag{9}$$

The dark lines parallel to the mirror are dark fringes, where no intensity is to be observed. They divide the triangular space into a system of parallel layers with practically no energy flow from one layer to the other, which proves once more that the resultant wave velocity V is directed parallel to the mirror. Figure 21 shows such interference pattern, as actually ob-

served with supersonic waves in water, when reflected on two rectangular mirrors.

There is no energy flowing through the dark fringes, and the same condition existing on the surface of the mirror is also fulfilled on each of these dark fringes. For instance, in the case of electromagnetic waves reflected from a conducting horizontal mirror M, the horizontal electric field vanishes at the mirror, it also vanishes on every dark fringe; thus we may,

FIG. 21.

Interferences between ultrasonic waves reflected on two mirrors at 45°.

without disturbing the interference pattern, put a second mirror M', parallel to the first mirror M, in one of these dark fringes. This is shown on Fig. 22, which represents a system of interferences propagating between both mirrors with phase velocity V. This corresponds to wave propagation inside a conducting tube, if we imagine a tube of rectangular cross section, one of the sides of said rectangle being infinitely long. The phase velocity is always given by formula (9) and is definitely greater than wave velocity W in free space, by a factor $1/\sin\theta$.

FIG. 22.

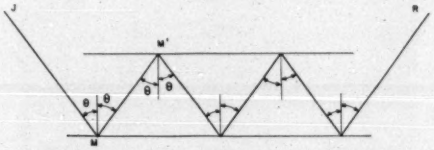
Interference fringes between two parallel mirrors.

The energy flow takes place with a different velocity U smaller than wave velocity W in free space

$$U = W \sin \theta, \tag{10}$$

a result which can be interpreted by considering the zig zag motion of a ray between mirror M and M' (Fig. 23). On the

FIG. 23.



Path followed by a ray reflected between two parallel mirrors.

other hand, angle θ is connected with the distance d between the mirrors because the integral number n of dark fringes is fixed. Hence

$$d = \frac{n\lambda}{2 \cos \theta} = \frac{nW}{2 f \cos \theta}. \tag{11}$$

Formulæ (9) and (10) yield relation (8). Eliminating θ from (9) and (11) one gets

$$\left(\frac{W}{V}\right)^2 + \left(\frac{nW}{2fd}\right)^2 = 1, \tag{12}$$

a relation represented by an elliptical curve as shown on Figs. 17 and 18, where ordinates are W/V and abscissæ, $\lambda/d = W/fd$.

Cut-off frequency f_1 corresponds to the limiting conditions

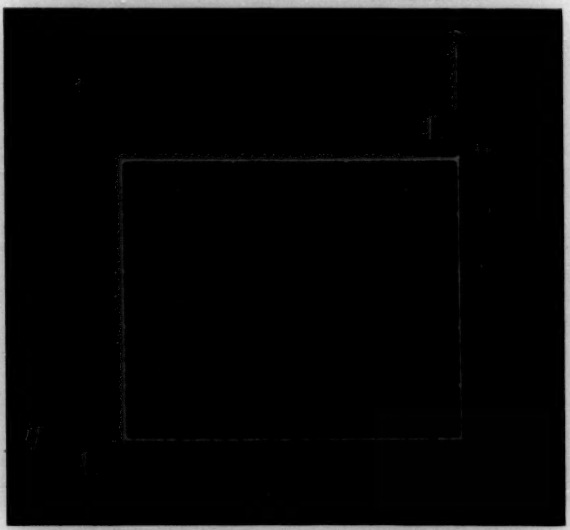
$$V = \infty, \qquad U = 0, \qquad f_c = n\frac{W}{2d}, \qquad \theta = 0. \qquad (13)$$

This very simple example is important to consider, as it yields directly the most typical features of guided waves inside hollow tubes, and enables an elementary explanation of the velocity relation. It should be kept in mind as a very valuable visualization of guided wave properties.

6. RECTANGULAR CROSS-SECTION.

This problem may be studied next, and presents no mathematical difficulty. Inside the cross section a typical interference pattern may be built up as shown in Fig. 24. Such a

FIG. 24.



Distribution of vibrations in the cross-section of a rectangular pipe.

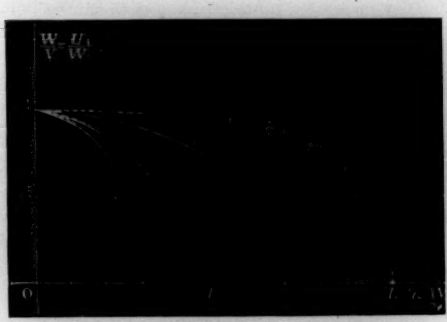
pattern is defined by two integers n_1 and n_2 giving the number of nodal lines in both directions. Theory yields the following relation for the phase velocity V inside the tube:

$$k^2 = \pi^2 \cdot \left[\left(\frac{n_1}{a} \right)^2 + \left(\frac{n_2}{b} \right)^2 \right], \tag{14}$$

$$\left(\frac{W}{V} \right)^2 + \left(\frac{kW}{2\pi f} \right)^2 = 1. \tag{15}$$

a, b, two sides of rectangular cross-section,
f, frequency,
k, proper value corresponding to the n_1, n_2 mode.

FIG. 25.



Set of elliptic curves giving the ratio of the velocity w of free waves to the phase velocity of waves propagating in a rectangular section pipe.

Formula 15 is represented by an elliptic curve, as shown in Fig. 25. Cut-off frequency f_c is obtained by making V infinite:

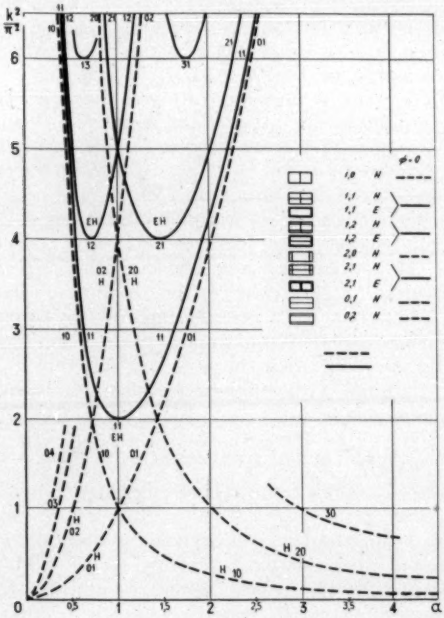
$$f_c = \frac{kW}{2\pi}. \tag{16}$$

Equations (14), (15), (16) are markedly similar to (12), (13) of the preceding section.

Writing down Maxwell's equations, one finds that each set of two integers $n_1 n_2$ may be used to define two distinct modes of vibration, one yielding an electrical wave and the

other a magnetic wave. These names are derived from the fact that the first wave possesses a longitudinal component for the electric field and no magnetic longitudinal component. Conditions are reversed for the so-called magnetic wave; the

FIG. 26.



Diagram—rectangular cross-section.

only difference to be noticed is that the electrical wave completely disappears when any one of the integers $n_1 n_2$ is zero, while magnetic waves can still be formed in this case.

It is a general result that the inverse proper value k^{-1} and the cut-off wave-length λ_c are proportional to the transverse dimensions of the cross section if the shape of its boundary is

maintained. This enables us to discuss the role played by the boundary shape, reducing the area of the cross section to a constant value, by taking

$$ab = 1.$$

Such a chart has been drawn in Fig. 26, showing the dependence of $(k/\pi)^2$ as a function of a; a equal to one means square cross section; $a > 1$ represents a rectangle with longer horizontal side a than vertical b.

Such a diagram is very interesting to discuss. One point should be emphasized relating to the stability or instability of different waves with respect to a deformation of the cross-section. Some curves ($n_1 = 1$, $n_2 = 1$ or 1.1 curve for instance) pass through a minimum for square cross section ($a = 1$) which means that a small alteration of the cross section will only slightly perturb the wave and its phase velocity. This wave type is stable; but other waves behave very differently. Let us consider the 0.1 and 1.0 waves which yield two distinct curves intersecting for the square cross-section. Any distortion from square cross-section to a slightly rectangular one will affect the wave by splitting it into two parts (0.1 and 1.0) with different velocities; such case corresponds to unstable waves.

7. CIRCULAR AND ELLIPTICAL CROSS-SECTIONS.

If interesting in itself, the case of tubes of rectangular cross-section is of no great practical value. Tubes are more likely to be built with circular cross-sections so that deformations then consist of alteration to an elliptical form. This explains why different authors [6] insisted upon treating the problem of wave propagation inside tubes of elliptical cross-section. Complete discussion leads to normal modes showing elliptical and hyperbolical nodal lines, as shown in Fig. 27. These proper modes of vibration are governed by Mathieu functions, on which numerical calculations prove rather troublesome. They yield charts similar in general aspect to the preceding

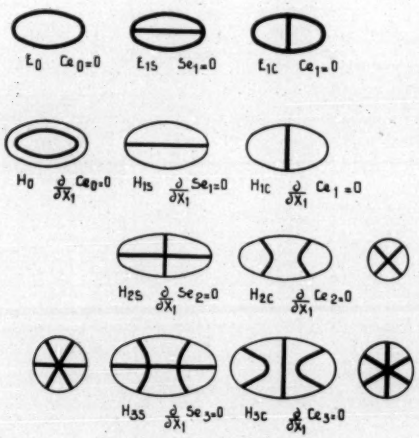
[6] L. Brillouin, *Electrical Communication*, 1938, 16: 350. L. Brillouin, *Bulletin Soc. Franç. Electriciens*, 1938, 8: 899. L. J. Chu, *Journal of Applied Physics*, 1938, 9: 583. Schelkunoff, *Journal of Applied Physics*, 1938, 9: 484.

one. Calling a and b the two semi-axes of the ellipse and keeping its area constant by taking

$$ab = 1,$$

one is able to draw the curves of Fig. 28 for electric waves and Fig. 29 for magnetic waves. Curves showing a minimum for circular cross section ($a = 1$) correspond to stable waves, while the unstable waves are represented by intersecting

FIG. 27.



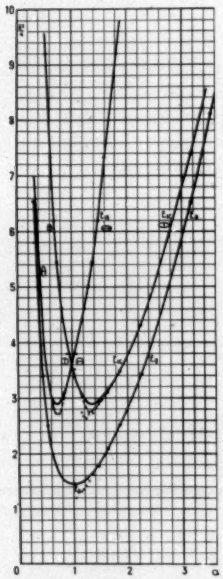
Nodal lines for elliptic cross-section.

curves. Thus the E_0 wave is stable; the E_1 wave is unstable (Fig. 28); the H_0 wave is stable, and the H_1, H_2 and H_3 waves are unstable (Fig. 29).

The very important point is the stability of H_0 waves, as these waves may prove to be of very great practical value, due to their small attenuation properties, as discussed in section 5, Fig. 19.

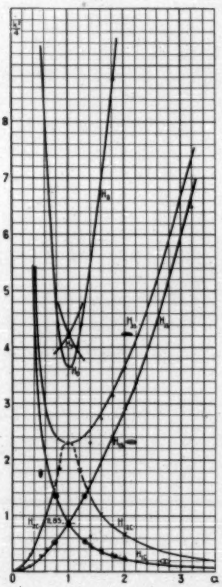
A great many interesting features could be deduced from the consideration of curves and charts shown in the preceding figures, but it would exceed the scope of this paper.

FIG. 28.



Electric waves.

FIG. 29.



Magnetic waves.

What should be emphasized as a conclusion is the great interest of hyperfrequency oscillations and waves, both for the physicist and for radio or telephone engineers. A new field of research is being opened here, with very curious theoretical and technical problems and a prospect for important practical applications.

THE ACCELERATED FLOW METHOD FOR RAPID REACTIONS.*

BY

BRITTON CHANCE.

PART II. DESIGN, CONSTRUCTION, AND TESTS.

I. APPARATUS CONSTRUCTION.

1. Design.

In the preceding part the fundamental design factors of the flow method have been discussed. It is now appropriate to design and build an apparatus having a high figure of merit according to the established criteria. The problem consists of constructing a fluid drive system to give a very high discharge rate with a minimum disturbance of the optical and electrical systems. A manual syringe drive should fulfil these requirements very well. It would afford a very flexible drive and should be well cushioned by the flesh to avoid mechanical shock to the apparatus. It is not apparent whether a sufficiently high rate of flow would be obtained with the force available in a reasonable time.

The plunger velocity and the syringe bore required to discharge the reactants through a 0.788 mm^2. tube at a maximum velocity of 20 m./sec. can be obtained and are indicated in Table V. The force on the plungers is calculated solely from the extrapolated value of 160 pounds per square inch pressure drop in a mixer and 0.788 mm^2. observation tube at a flow of 20 m./sec. In addition to this hydrostatic force there will be an inertia force due to the rapid acceleration.

Table V shows that there is a very wide choice of values of plunger velocity and plunger force. There are in general the following ways of driving the syringes:

1. Mechanical: Hydraulic, compressed air, spring loaded plunger, falling weight, or rifle bullet.

* Contribution from the Department of Chemistry and Chemical Engineering of the University of Pennsylvania and the Physiological Laboratory, Cambridge, England.

TABLE V.

Design Constants for Accelerated Flow Method Calculated on a Basis of Maximum Flow Rate of 20 m./sec.

Max. Velocity of Plungers (ft./sec.).	Height of Falling Weight (ft.).	Force on Plungers (lbs.).	Area of Plunger mm.².	Diameter Plunger mm.
25.9	10.9	0.808	1.0	1.13
13.0	2.72	1.62	2.0	1.59
6.5	0.68	3.23	4.0	2.25
2.6	0.109	8.08	10.0	3.56
1.78	0.052	11.0	14.5	4.30
1.29	0.027	16.2	20.0	5.04

2. Electrical: Solenoid or electric motor.
3. Manual: Direct push.

Each type of drive has an optimum range. The first is well fitted to drive very small bore syringes (1–2 mm.) at very high rates. The second is best for large syringes (5–30 mm.) where large forces at low speeds are required. The manual drive should be appropriate for the medium size syringes (3–5 mm.).

Tests of a manual drive were made with 0.3 cc., 2 mm. bore, 1 cc., 4 mm. bore and 50 cc., 29 mm. bore syringes working into the same type of mixer. The results are in accord with Table V. Insufficient flow velocity was obtained with the 0.3 cc. syringes while the required force was too great with the 50 cc. syringes. The 1 cc. tuberculin type syringes permit a discharge of 23 cc. per second using one finger. It is possible that a little larger power output could be obtained by using a larger bore syringe but it is felt that some of the accurate control of flow velocity range would be lost if the finger were more heavily loaded. The main source of mechanical shock to the optical and electrical system is due to the sticking of the syringe plungers during discharge. Mechanical sticking of the syringes is extremely important for this reason. The metal plunger type are far superior to the all glass syringe in this respect.

2. Mixer Construction.

Several all glass mixers of an opposed piston type have been constructed. These are constructed according to the

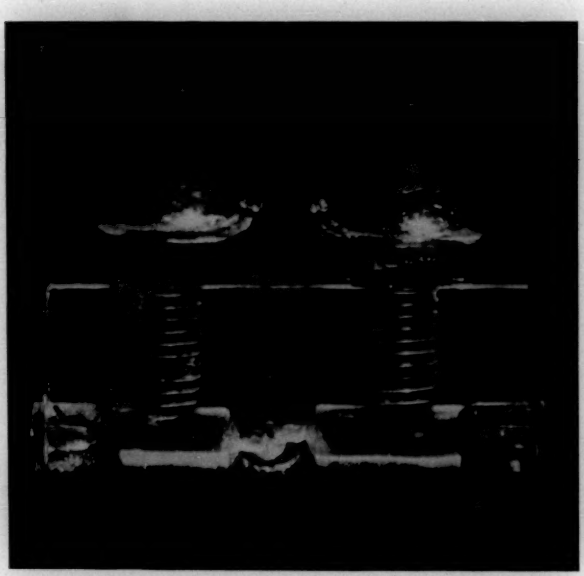
methods described under pressure drop studies and have proved generally satisfactory but expensive to build and difficult to alter. As the study of the effect of jet design on cavitation necessitated the construction of a large number of readily interchangeable mixers, polystyrene was found to be a very useful material for this purpose. Several mixers were made by molding the material about a copper form of the mixing chamber and subsequently dissolving out the copper. These were inferior to those made by drilling the holes from a solid block of material. There were two problems that had to be overcome. Tight connections were needed where the mixer joined the syringes and the observation tube. It was found that the syringes could be threaded and screwed into the polystyrene. When a rubber band was used as a gasket the joint did not leak at the highest driving pressures used. As glass observation tubes were favored it was necessary to make a glass to polystyrene seal. It was found that this could be done very simply by heating the glass tube and plunging it several millimeters into the plastic. The seal is so strong that the tube must be broken before it can be withdrawn. Thin wall tubes will sometimes crack out and Pyrex tubes make the best seal. This seal has been made with lucite and a polystyrene polymer of a rather high softening point. This last substance is superior to the others in that it makes the best seals and resists organic solvents to a much greater extent than the others.

Units employing all glass syringes have been made in a similar manner by using a Luer to screw connector between the syringe and mixer. Units have also been made where the syringes have been directly sealed into the mixer.

The construction of a typical mixing chamber will now be described. First, drill the two holes for the syringe tips. Draw a line between the ends of the two holes. Heat the observation tube (it may not be quite as long as the available drill) and plunge it into the styrene at the midpoint of the line. Take the drill that just fits the observation tube and drill up through the end of the observation tube to clear out the styrene that has solidified there. Continue drilling until the hole is two mm. past the end of the observation tube. Now drill two 2 mm. holes in towards the end of the observa-

tion tube. These holes will intersect the two syringe holes at right angles and follow the line drawn between their ends. Bring these two holes to within 2 mm. of the extension of the observation tube. Now follow up the hole with a 0.5 mm. drill and drill two jet holes on each side into the extension

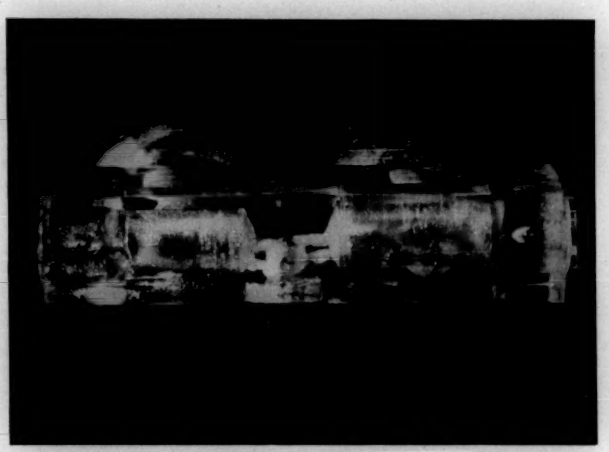
FIG. 17.



Lucite mixing chamber showing tangential jets and rear of observation tube seal.

of the observation tube. These two jets should be side by side along the axis of the observation tube. Those on one side are high and those on the other side low with reference to the observation tube. Now tap the syringe holes, screw the syringes into the proper holes and seal in glass plugs for the other two. A four jet mixer is now completed. An eight

FIG. 18.

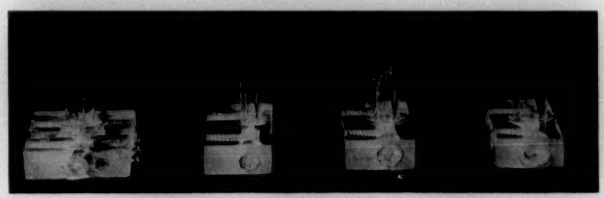


Lucite mixing chamber showing double jet arrangement, observation tube seal, and glass observation tube.

jet mixer has been made by drilling two jets in from each of four larger holes, much in the way described.

This mixer is illustrated in Figs. 17 and 18. Figure 17 shows a back view looking parallel to the observation tube and shows the tangential jets. Figure 18 is a bottom view

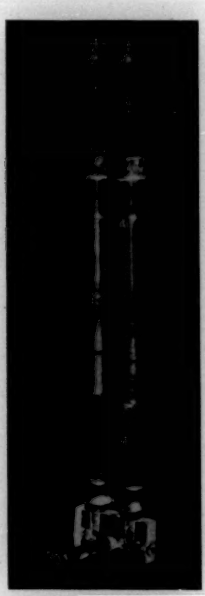
FIG. 19.



Polystyrene mixing chambers of various observation tube bores. From left to right—eight 0.4 mm. jets, 1 mm. bore tube; four 0.6 mm. jets, 1.8 mm. bore tube; six 0.6 mm. jets, 3 mm. bore tube; six 0.6 mm. jets, 3.8 mm. bore tube.

and shows the double jets. Figure 19 shows four mixers of increasing observation tube bore constructed in this manner and used for studying reactions where the signal to noise ratio of the photoelectric system is the limiting factor.

FIG. 20.



Complete syringe units using two one cc. tuberculin type record syringes.

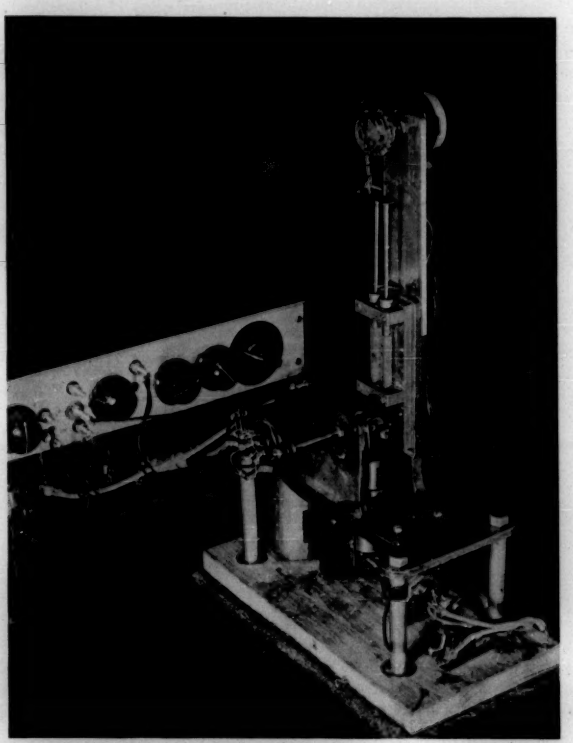
All these mixers are readily attached to syringes as in Fig. 20. The syringes are then placed in a brass plate and held by split collars packed with string. This unit fits directly into the apparatus.

3. Apparatus Construction.

The final form of the apparatus is shown in Fig. 21 and consists of a single bronze casting which carries all the com-

ponents of the accelerated flow machine. The horizontal part of the casting carries the lamp, lens, and light control amplifier

FIG. 21.

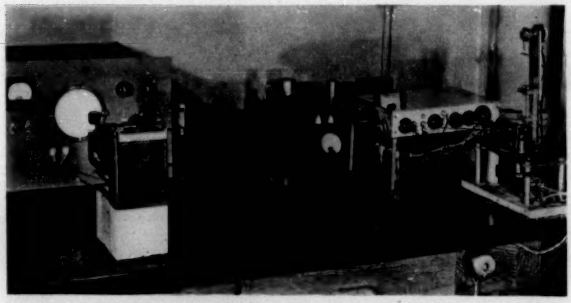


The accelerated flow apparatus and amplifier.

tube while the vertical part carries the syringe plate, flow velocity indicator, the photometer photocell and amplifier tube. The upright carrying the syringe plate has a rib in

back to minimize any bending of the support during a rapid discharge. The syringe plate is held to this rib by four screws in slots so that the observation tube may be exactly aligned with the light beam. The flow velocity potentiometer is mounted on top of the plate attached to the upright. The lens is a commercial sound track lens and contains a condenser, adjustable slit, and a microscope objective. While this is not quite as efficient as the smaller sound track lenses using crossed cylindrical lenses, the adjustable slit is a desirable feature. The lens gives a beam 3 mm. long and 0.025 mm. wide. Color filters are placed on top of the lens. The lamp, a 32 or 75

FIG. 22.



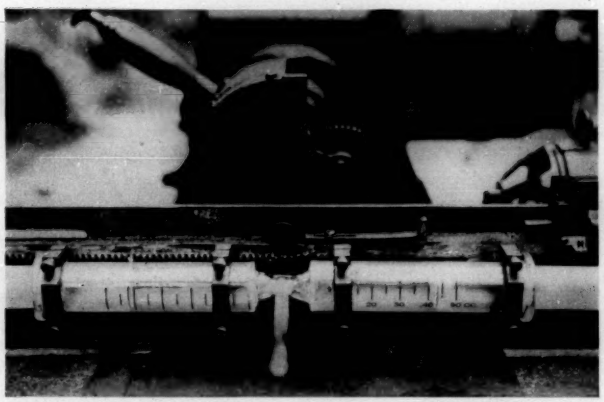
The complete apparatus for the accelerated flow method.

watt sound track exciter lamp, is held against the lens by a strap to prevent any relative motion during a rapid discharge. The observation tube is connected to a two-way stop-cock by rubber tubing through a hole in the smaller upright (not shown). A cover is used to shield the photometer photocell from electric fields and stray light. The amplifier, power supplies, cathode ray tube, and camera appear in Fig. 22.

It is well to note that the accelerated flow method can be directly applied to the previous types of apparatus as used by Millikan.[2] The antecedent of the present apparatus shown in Fig. 23 illustrates this very clearly. A 1/6 h.p. motor drives the directly opposed all glass syringe and mixer

unit through a variable gear box and two opposed racks. The flow velocity indication is obtained from a small generator belted to the motor. The e.m.f. of the generator is proportional to the flow velocity. A lamp and photocell unit measures changes in light absorption. The measurements were made by starting and stopping the motor and recording the variation of the extent of reaction on the cathode ray tube as a function of the flow velocity.

FIG. 23.



Motor driven syringe unit with horizontal opposed all glass syringe unit and belted generator for flow base.

Several features of the design are noteworthy. At flow rates of 20 m./sec. the 1/6 h.p. motor has all the load it can stand—a smaller motor would not do. The variable gear box is really a great help not only in adjusting the load torque to suit the motor but also to make observations at known and reproducible fractions of a constant motor speed. The opposed syringe design theoretically takes all the hydraulic thrust off the syringe clamps as the hydraulic forces should balance. In practice this is found to be the case at all times except when one of the plungers jams and this causes distor-

tion of the clamping system. A dynamic braking system is necessary when using fast rates of flow because the motor has sufficient inertia to coast far enough to smash the limit switch or the syringes after the current is turned off.

This apparatus gives very satisfactory results for flows up to 10 m./sec. For flows above this the motor vibration starts the exciter lamp vibrating and gives rise to an a.c. in the photocell output. For recording slow changes in light absorption, this would be no disadvantage as the integral of the vibration over a period is zero. One disadvantage of the apparatus is the electrostatic and electromagnetic effects of the motor upon the photometer.

It was possible to make a direct comparison of the manually and electrically driven units both employing the accelerated flow method. The data obtained from the electric drive was more uniform and somewhat more accurate as the acceleration of the flow could be controlled quite well by a dynamic braking system. The time range of the electric drive was somewhat less than that of the manual drive as the 1/6 h.p. motor was overloaded at flow velocities above 20 m./sec. The obtainable signal to noise ratio of the photoelectric systems showed a very large contrast. The vibration of the lamp, the pick-up from the motor, and the microphonics in the amplifier adversely affect the photoelectric system of the motor driven unit even though these effects were somewhat reduced by observing when the acceleration was negative since the current is cut off from the motor during this period. It was also possible to obtain greater mechanical stability with the manually driven unit.

II. THE EXPERIMENTAL PROCEDURE.

1. Color Calibration.

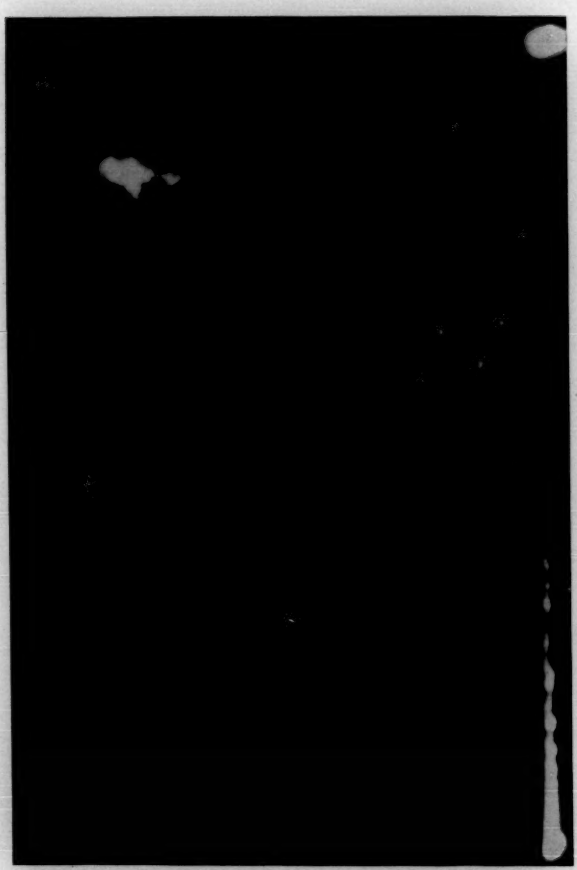
The spectral absorption bands of both reactants and the end product are obtained from published data or by a hand spectroscope with a direct reading scale. A filter combination is then selected so that the change of absorption between one reactant and the end product is large. The syringes are then filled with the reactants.

The syringes have been previously filled with distilled water. The observation tube connects to a two-way stop-

cock connecting to waste or to distilled water. One syringe plunger is withdrawn, the valve turned to waste and the syringe drained until the water level just reaches the base of the syringe when the stop-cock is turned off. Reactant A is now squirted down the open end of the empty syringe until it is full. The plunger is entered, the stop-cock turned to waste and the plunger inserted one-half inch. The plunger is held in place by the pushing block and chain to the flow velocity indicator potentiometer. The second syringe is now discharged to waste to clean out the observation tube. When it reaches the bottom the stop-cock is turned to distilled water which is sucked up into the syringe. The plunger is completely withdrawn allowing the water to drain to waste after the stop-cock is turned in that direction. When the water has drained down to the base of the syringe the stop-cock is turned off and the empty syringe is now filled with reactant B from the top. The plunger is entered, the stop-cock turned to waste and the plunger pushed down until it can be screwed into the pushing block.

The observation tube is now filled with reactant B. The amplifier and oscillograph are turned on and the base line is adjusted to zero. The observation tube is next filled with reactant A by pushing that syringe plunger. The deflection of the oscillograph is then noted and is adjusted to a reasonable magnitude by altering the sensitivity control. Both plungers are now screwed into the pushing block and the deflection due to $A + B$ is measured. In the usual case $A + B$ gives the same deflection as A so that the kinetic change will be from B to $A + B$. The maximum kinetic deflection will be 1/2 the static calibration since B is diluted to 1/2 strength by A. This is true only if A is in large excess or has very small absorption at the wave-length used. Figure 24 shows the case where $A + B$ absorbs light and A and B do not. The kinetic deflection is then equal to the static deflection. It is customary to test the linearity of the absorption measurement by comparing the deflection due to reactants diluted 1/2 to the deflection of undiluted reactants. There is considerable a priori reason for assuming that the calibration should be linear for substances obeying Beer's law since the sensitivity control is arranged so that a light trans-

FIG. 24.



Typical flow curve obtained by the accelerated flow method where the kinetic deflection approaches the static calibration (dot in upper right hand corner) (Reactants: Sodium tungstate and titanous chloride). The horizontal axis is flow velocity and the vertical axis is light absorption.

mission change greater than 3 per cent. will be off scale at minimum sensitivity.

2. Anaerobic Operation.

The apparatus can be adapted for anaerobic operation by constructing syringes having a small port near their upper end through which reactants could be admitted under

FIG. 25.

A flow curve obtained under anaerobic conditions. Luciferin and luciferase are mixed under anaerobic conditions. The curve shows the course of the luminescence when the substances are mixed with oxygen.

anaerobic conditions. This port is then closed by the syringe plunger itself very much as in the two cycle engine. An alternative method which has been used is to connect the exit of the observation tube to a source of oxygen free hydrogen. The hydrogen is passed through the reagents, the stop-cock, and the observation tube. One syringe is filled with the oxygenated reagent and the plunger is entered. The hydrogen flows out of the other syringe and inward diffusion of

oxygen is prevented by a small piece of cotton at the end of the syringe. After a few minutes flushing with hydrogen the vessel containing the anaerobic reagent is tilted so that the reagent is then forced up onto the syringe under an atmosphere of hydrogen. The plunger is entered and the kinetic curve is obtained as before, see Fig. 25. In experiments on luciferin and luciferase * under anaerobic conditions the limiting factor has been the oxygen dissolved in the stop-cock grease and not the extent to which the oxygen could be flushed out of the syringe.

3. Kinetic Runs.

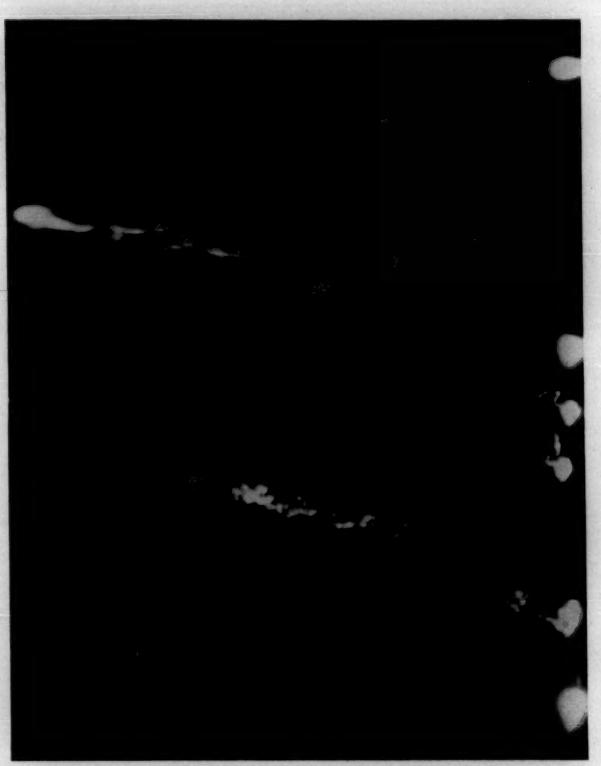
After the sensitivity has been adjusted so as to give a satisfactory deflection for the static calibration, the material remaining in the syringes is used for kinetic runs. The flow velocity indicator is recorded on the horizontal axis of the oscillograph and the change of light absorption is recorded on the vertical axis. The pushing block is given a rapid, sharp push and simultaneous values of flow velocity and change of light absorption appear on the cathode ray screen as a moving spot. If the reaction is very rapid a curve similar to Fig. 26 will be obtained. There is usually enough material in the syringes to permit a duplicate run as shown. If, however, the reaction is slow the extent of reaction will be very small when the flow has stopped. Such a reaction is observed by the stopped flow method as shown in Fig. 27. The flow velocity indicator is replaced by a linear time base which moves the spot across the screen at a uniform rate. When the end of the screen is reached the spot very rapidly returns to the other end of the screen and repeats the cycle. The extent of reaction is then measured as a function of time directly. Between three and five "stop" curves may be obtained for one filling of the syringes.

4. Calculation of Results.

The photographic results obtained by the stopped flow method are immediately useful in obtaining the reaction velocity constant. The time is always marked on the photo-

* See Chance, Harvey, Johnson, and Millikan, J. Cell. and Comp. Physiology, *15*, 195 (1940).

FIG. 26.



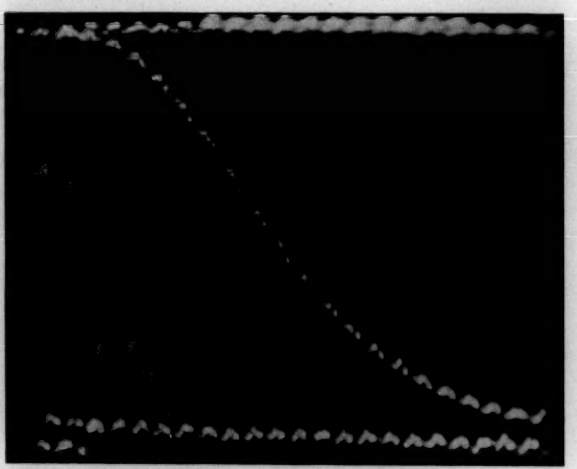
Typical flow curves of a rapid reaction obtained by the accelerated flow method (Reactants: Ceric sulfate and potassium iodide).

graph by a 50 or 60 cycle timing wave superimposed on the photoelectric system. The logarithm of the extent of reaction may be plotted directly against time. This has been done in Fig. 31. A flow curve is usually taken after a "stop" curve so

that the extent of reaction when the flow stops may easily be determined. If this is small, the origin of time is taken at the point where the extent of reaction is zero.

If the extent of reaction is considerable when the flow stops, points from the "flow" curve may be used to supplement data from the "stop" curve. The acceleration should

FIG. 27.



Typical curve obtained by the stopped flow method (Reactants: Potassium permanganate and hydrogen peroxide in acid solution). Time markers 1/50 second.

be small or the points from the "flow" curve will be in error as indicated by (45) or (55). Alternatively the extent of reaction when the flow stops may be greatly decreased by increasing the acceleration.

The photographic results obtained by the accelerated flow method can be converted into the conventional form by replotting the flow velocity axis in reciprocal or time units. The scale factor for this axis is determined as described under the flow velocity indicator. In this case the reaction should be essentially complete before the flow stops as indicated in

Fig. 26. If this is not the case the value of acceleration used should be reduced. Under these conditions the "flow" curve is valid as shown on the photograph. If it is desired to correct points measured when the extent of reaction is small and the acceleration large, expression 55 may be used for this purpose. It is felt, however, that the expressions should be used only to evaluate the conditions under which the apparatus gives direct results. This particular apparatus is now adjusted to measure reactions of $t_1 \leq 1 \times 10^{-3}$ seconds with a maximum error of 2 per cent. of the total extent of the reaction due to slit length and acceleration (Fig. 12). It would not be difficult to measure a longer time with as small an error although there would be a definite sacrifice in fluid economy.

In the data that follow the concentration of reactants is given in moles per liter and is the concentration of reactants after mixing in the observation tube. The half-times of the "flow" curves are in seconds and are the measured time for half completion of the reaction. The k_1 values are the average of three points taken from the experimental curve where the extent of reaction is small and are calculated on the assumption that a logarithmic equation holds. The k_2 values are obtained by dividing the k_1 values by the concentration of the reagent in excess.

The data from the "stop" method are usually over the full extent of the reaction and the values of k_1 are obtained from the slope of the curve showing logarithm of extent of reaction against time. The k_2 values are again obtained by dividing the k_1 value by the concentration of the reactant in excess. It is not to be inferred from the use of the value k_2 that any reaction has been proven to be bimolecular, for k_2 is only used as a number to express simultaneously rate and concentration.

III. EXPERIMENTAL TESTS.

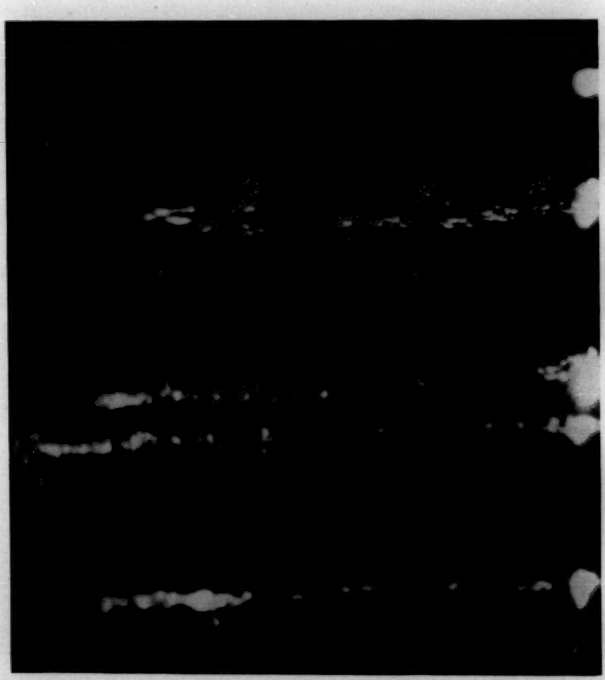
Experimental tests have been made with the accelerated and stopped flow apparatus to justify and to demonstrate the applicability of the analysis of Part I and to obtain evidence for experimental controls of the method. A brief survey of some measurable reactions of inorganic chemistry has been

included to demonstrate that the range of the present apparatus includes many reactions suitable for a detailed study of their mechanism.

1. Cavitation and Mechanical Distortion.

These factors have been shown to influence the attainable flow velocity and the signal to noise ratio of the photoelectric system when the extent of reaction is measured by a change in

FIG. 28.



Upper two curves: Test of cavitation and mechanical distortion. Lower two curves: Test of efficiency of mixing. Reactants: 5×10^{-4} N iodine and thiosulfate.

light absorption. Both phenomena appear as a variation of light transmission as a function of flow velocity. Cavitation appears as a sharp and very large decrease in light transmission of the flow stream and occurs at a given high value of flow velocity, but once started does not disappear until a much lower value of flow velocity is reached.

Mechanical distortion, whenever observed in the development of this apparatus, has appeared as an increase or decrease of light transmission whenever a large driving force is exerted on the syringe plungers. This distortion causes a relative movement of the parts of the optical system and can thereby cause a change in light transmission.

The development of the apparatus has permitted a reduction of both these factors to such an extent that they are within the inherent error of the photoelectric system.

The control developed for simultaneously evaluating these errors consists of simply discharging water through the observation tube at all values of flow velocity used in actual experiments and measuring any light transmission change due to these two errors by the photoelectric system which must be operated at the highest sensitivity used in actual experiments. A record of this test is shown in the two upper curves of Fig. 28 where a flow velocity of 23 m./sec. was attained and the photoelectric system was operated at full sensitivity. If there were no error due to these factors the photograph would consist of a horizontal line. In this test the line is quite horizontal and the transmission change due to cavitation and mechanical distortion was on the order of the photoelectric error or about two per cent. The error corresponds to a transmission change of one part in 5000.

2. Mixing.

The analysis has shown that the efficiency of mixing is of utmost importance to obtain a high figure of merit in the time limited case. It has also been shown that the efficiency of mixing becomes of secondary importance in substance limited cases. It is in any case necessary to establish that the mixing is essentially complete under the conditions for measurement of kinetic data.

The most satisfactory type of mixing test for a photo-

electric apparatus consists of measuring the extent of a reaction known to be complete in a time shorter than the shortest time measurable by the system.

To fulfil this requirement it would be advisable to select a reaction showing bimolecular characteristics and to measure its rate in dilute solutions. The rate can then be increased by increasing the concentration of the reactants until the reaction is no longer measurable by the system. In this way the increase of rate required to make the reaction too rapid to measure is obtained. If the required increase of rate is much greater than one would expect on the assumption that the reaction is bimolecular, or if the extent of reaction does not change upon an increase in the concentration of the reactants, the mixing is probably not complete at the point of observation.

Two very rapid reactions have been used for this purpose. The first reaction is between iodine and thiosulfate. When the concentration of both reactants is 5×10^{-4} N the reaction is about 96 per cent. complete at the shortest time measurable (0.3×10^{-3} sec.). The concentration of the thiosulfate is doubled and the extent of reaction falls within the error of measurement. The lower two curves of Fig. 28 show this test. Again, as the vertical axis represents light absorption the evidence for the completion of the reaction would be a horizontal line. The observed line is horizontal within the experimental error. The possible error of mixing is then this error of 2 per cent. from which the mixing is shown to be 98 per cent. complete at the point of observation (10 mm.) at all flow velocities used. The reaction of ceric sulfate and hydrogen peroxide provided a second mixing test. In this case 4×10^{-3} N solutions were used and the extent of reaction was 60 per cent. On increasing the concentration of the reactants the extent of reaction increased to 98 per cent. or to within the photoelectric error.

3. The Dilution of Concentrated Solutions.

An error of light transmission measurements which is to be avoided with this apparatus is an effect which occurs due to the dilution of concentrated solutions. It has been observed that a 10 per cent. ammonium sulfate solution gives an

apparent increase of light transmission over that due to water in a circular capillary tube. This is probably due to the change of refractive index. This change of transmission is also a function of flow rate and may constitute a sensitive mixing test. Before such a "reaction" may be used for a mixing test, relations between light transmission and per cent. of mixing need to be developed.

4. The Value of Acceleration.

Before the limits to the operating ranges of the accelerated and stopped flow methods can be set it is necessary to deter-

FIG. 29.

Determination of acceleration: Flow velocity against time (Time markers 1/60 second).

mine the value of the acceleration of the flow. If the drive were mechanical this value could be set at will. As the drive is manual the value of acceleration will depend upon the

TABLE VI.

Summary of Kinetic Data.

Experiment.	Reactant *A*.	Concentration.	Reactant *B*.	Concentration.	No. of Experiments.	Filter No.*	$t_{\frac{1}{2}}$ (sec.).	k_1.	$\frac{k_2}{1}$ mol. sec.	Method.
1	Potassium Bichromate Sulfuric Acid	2.38×10^{-4} M 0.1 N	Hydrogen Peroxide	0.02 M	3	—	0.0183	38	1,900	SFM
2	Methylene Blue	0.0025%	Ceric Sulfate	6.9×10^{-6} M	1	—	0.043	16	230,000	SFM
3	Methylene Blue Methylene Blue	0.0025% 0.0025%	Titanous Sulfate Titanous Sulfate	3.17×10^{-3} M 6.34×10^{-3} M	1 1	— —	0.050 0.028	14 25	4,400 4,000	SFM SFM
4	Ferric Alum Ferric Alum Ferric Alum	5.75×10^{-4} M 5.75×10^{-4} M 5.75×10^{-4} M	Ammonium Thiocyanate Ammonium Thiocyanate Ammonium Thiocyanate	0.034 M 0.064 M 0.117 M	1 1 1	— — —	0.0012 0.00069 0.00029	600 1,000 2,000	18,000 16,000 17,000	AFM AFM AFM
5	Ceric Sulfate	4.29×10^{-3} M	Potassium Iodide	0.0377 M	1	7	0.00055	1,200	33,000	SFM
6	Sodium Iodate	1.25×10^{-3} M	Potassium Iodide	0.0150 M	1	7	2.35	0.300	20	SFM
7	Titanium Sulfate Titanium Sulfate Titanium Sulfate Titanium Sulfate	6.34×10^{-3} M 6.34×10^{-3} M 6.34×10^{-3} M 6.34×10^{-3} M	Hydrogen Peroxide Hydrogen Peroxide Hydrogen Peroxide Hydrogen Peroxide	0.04 M 0.02 M 0.01 M 0.004 M	1 3 1 1	7 7 7 7	0.035 0.080 0.120 0.230	20 8.6 6.0 3.0	500 430 600 750	SFM SFM SFM SFM
8	Ceric Sulfate	4.29×10^{-3} M	Hydrogen Peroxide	2×10^{-3} M	1	7	0.00041	1,700	860,000	AFM
9	Potassium Permanganate Sulfuric Acid	1.8×10^{-4} M 0.1 N	Hydrogen Peroxide	2×10^{-3} M	1	5	0.130	5.8	2,900	SFM
10	Potassium Bichromate Potassium Bichromate	1.19×10^{-2} M 2.38×10^{-2} M	Sodium Hydroxide Sodium Hydroxide	0.05 M 0.10 M	3 3	5	0.100 0.037	6.8 19	136 190	SFM SFM

* Filter numbers refer to Chance Filters, Birmingham, England. Temperature of experiments 18° C.

operator. The electrical apparatus already required in these methods contains the means for determining this quantity. The syringes are discharged manually in the usual manner. The flow velocity is recorded on the horizontal axis. The time base, usually employed for stopped flow recording, is applied to the vertical plates. The trace obtained gives the relation between flow velocity and time and the slope of the curve is the acceleration of the flow. A typical curve is shown in Fig. 29 for this apparatus. This curve is taken with an automatic brilliancy control so that the trace representing negative values of acceleration shows clearly. The value of the acceleration is about 200 m./sec.^{2} which limits the range of the accelerated flow method to values less than 10 milliseconds and the range of the stopped flow method to values greater than 30 milliseconds for this particular value of acceleration, distance from the point of mixing, and observation tube bore. It is found that the value of acceleration can be held reproducible or varied over a narrow range at will by the manual drive. The results in Table VI are in accord with Fig. 12, Part I, as no reaction measured by the accelerated flow method and having a value of k_1 smaller than 600 has been included.

5. The Speed of Response and Sensitivity of the Photoelectric System.

The speed of response of the photoelectric system must be large enough to measure the most rapid light intensity change occasioned by the largest value of acceleration of the flow attainable. The response speed is easily measurable by apparatus already existing in the method. The horizontal axis is supplied by the time base as for stopped flow recording. Both syringes are filled with a colored solution. The observation tube is still filled with water so that when the syringes are rapidly discharged a very sudden change of light transmission occurs. The response to this sudden change is recorded as a function of time on the vertical axis of this oscillograph. The response time of this amplifier is less than 0.01 second at full gain. The experimental trace is not reproduced here because the writing speed of the recording system is taxed by this test and the trace is too faint.

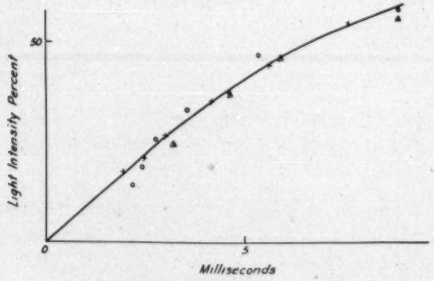
The sensitivity of the photoelectric system is such that a

10^{-7} molar solution of methylene blue and a 10^{-5} molar solution of iodine can be measured with an accuracy of 10 per cent. in a 1 mm. tube in a time of $\frac{1}{100}$ second. The sensitivity to luminous reactions is such that 0.05 cc. of a strong suspension of luminous bacteria (Ph. Fischeri), 0.05 cc. of a 3 per cent. solution of luciferin and luciferase from Cypridina, or 0.05 cc. of a 0.03 per cent. solution of 3 amino phthalhydrazide treated with 0.008 per cent. H_2O_2 and 0.06 per cent. ferricyanide can be measured with an error of 3 per cent. and a speed of response of $\frac{1}{100}$ second.

6. Kinetic Tests.

The kinetic tests are included to show the experimental range, accuracy and reproducibility of the accelerated and stopped flow methods.

FIG. 30.



Reproducibility of the data obtained by the accelerated flow method. Reactants: Luciferin, luciferase, and oxygen.

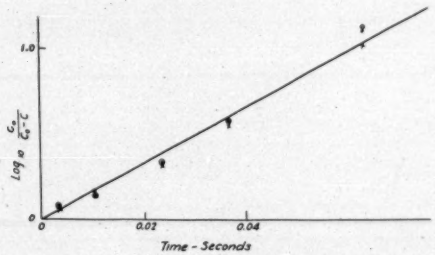
The reproducibility of results obtained by the accelerated flow method is demonstrated in Fig. 30 showing three successive experiments on a luminous reaction. The maximum discrepancy of any point from the smooth curve is 5 per cent.

The results of three successive experiments with the stopped flow method are plotted in Fig. 31. The maximum

deviation from the mean of the three sets of points is 2 per cent. The maximum deviation between any two curves is 3 per cent. Those points in Fig. 31, corresponding to times smaller than 30 milliseconds are not used to demonstrate the time range of the stopped flow method and can only be used to do so if the assumption is made that the reaction involved follows a logarithmic curve and has no induction period.

The time range of the accelerated flow method is shown in Fig. 32 where a rapid reaction is measured at three rates by doubling the concentration of the reactant in excess for each curve. The shortest time measured is 0.3 millisecond.

FIG. 31.

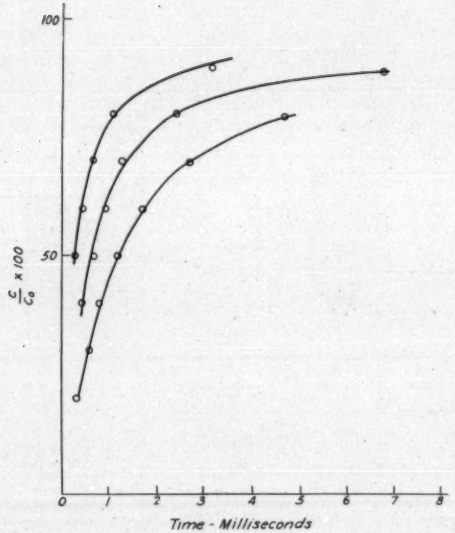


Reproducibility and time range of data obtained by stopped flow method (Reactants: Potassium bichromate and hydrogen peroxide in acid solution). Experiment 1, Table VI.

A summary of a short survey of the measurable reactions of inorganic chemistry is given in Table VI.

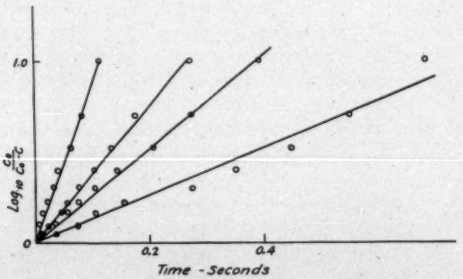
The pH of all these reactions is that of the reactants themselves in aqueous solution unless otherwise noted in Table VI. The temperature of the reactants is that of room temperature or 18° C. While all the reactions tested showed a variation of rate with the concentration of the reactants, only a few have been studied in sufficient detail to demonstrate bimolecular characteristics over a short range. These include the reactions of ammonium thiocyanate and ferric alum shown in Fig. 32 and measured by the accelerated flow method, titanium sulfate and hydrogen peroxide shown in Fig. 33 and measured by the stopped flow method, and potassium bichro-

FIG. 32.



Time range of the accelerated flow method (Reactants: Ferric alum and three values of ammonium thiocyanate concentration). Experiment 4, Table VI.

FIG. 33.

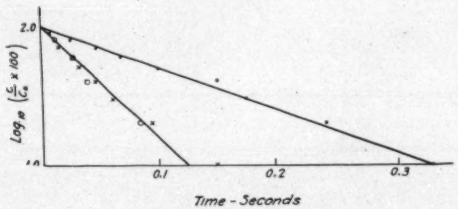


The reaction of titanium sulfate and hydrogen peroxide. Titanium sulfate: 6.34×10^{-3} M. Hydrogen peroxide: 0.04, 0.02, 0.01 and 0.004 M. Experiment 7, Table VI.

mate and sodium hydroxide shown in Fig. 34 and also measured by the stopped flow method.

A group of very rapid reactions tested includes the reactions of iodine and thiosulfate, iodine and sulfite, ceric sulfate and hydrogen peroxide, chromate and acid, phenolphthalein and alkali, permanganate and ferrous sulfate, and permanganate and iodide in acid solution. The half time in all these reactions at the highest dilutions measurable was less than 0.3 millisecond. The velocity constants k_2 for the two iodine reactions are greater than 10^6. The reaction between methylene blue and ceric sulfate was also rapid but the extinction

FIG. 34.



The reaction of potassium bichromate and sodium hydroxide. Potassium bichromate. 1.19×10^{-3} M and 2.38×10^{-3} M. Sodium hydroxide: 0.05 M and 0.10 M. Experiment 10, Table VI.

coefficient of methylene blue is so large that it was possible to use extremely dilute solutions and the reaction was measured by the stopped flow method. k_2 was found to be 230,000. k_2 for the reaction of ceric sulfate and hydrogen peroxide is approximately 860,000.

IV. SUMMARY.

A manual syringe drive has been found to fulfil the requirements for a high driving force and a small disturbance to the electro-optical system. A syringe bore has been selected with due regard for the force-speed characteristic of the hand and flow velocities of 25 m./sec. have been obtained in this manner. A direct comparison of a manual and an electric drive has been made and it has been found that the mechanical and electrical effects of the latter upon the photoelectric system greatly reduce the possible range of the electric drive method.

In order to avoid troubles due to stop-cocks and other connections between the mixing chamber and syringe unit, the syringes are screwed into the mixing chamber directly and the syringes are filled from the top. Difficulties due to connections between the mixing chamber and observation tube have been avoided by sealing the glass observation tube into the lucite or polystyrene mixing chamber. The plastic mixing chamber is very suitable for making multi-jet mixers. The mixing of such units is 98 per cent. complete at all obtainable flow velocities at 10 mm. from the point of mixing.

It has been found experimentally that the jet placement will affect the flow velocity at which cavitation occurs. A compromise between directly opposed and tangential jets has been found most satisfactory. The transmission change due to cavitation is within the photoelectric error at a flow velocity of 25 m./sec.

In order to obtain a high value of signal to noise ratio in the photoelectric system a very efficient light source slit and lens combination was used in conjunction with combinations of color filters. The photocell was also chosen with regard to its sensitivity for the particular wave-length of light used. Using photoelectric light control a transmission change of one part in 10,000 was measurable. The time of response of the amplifier was less than 0.01 second under these conditions since this time determined the possible fluid economy.

The value of acceleration achieved by the manual drive was about 200 m./sec.^{2}. This high value was desirable as it permitted a very high fluid economy. Two kinetic curves were obtained from one cc. of each reactant in this manner. Due to this high fluid economy the range of recording of the accelerated flow method was limited to times shorter than 10 milliseconds. This was not found undesirable as the stopped flow method was used for times greater than 30 milliseconds. If the fluid economy were not important it would be possible to reduce the value of acceleration and record much longer times by the accelerated flow method. The flow velocity has been determined as a function of time and it is found that the negative values of acceleration are essentially constant.

The time range of the accelerated flow method is from 0.3 to 10 milliseconds. The shortest time is limited by the force

available from the manual syringe drive and the longest time is limited by the magnitude of acceleration as described above. The time range of the stopped flow method is from 30 milliseconds to 60 seconds. The shortest time measurable here is limited by the magnitude of the acceleration and the longest time measurable is limited by the slow drifts of the photoelectric system.

The accelerated and stopped flow methods have been used for surveying some measurable reactions of inorganic chemistry. In nearly all cases tested the rate of reaction was increased on increasing the concentration of the reactants. The rates of reaction were usually measured at the greatest dilutions made possible by the photoelectric system. The value of half time measured depended upon the extinction coefficient of the substance. It is therefore difficult to set a limit on the highest value of a velocity constant k_2 measurable by the apparatus. The value of k_2 for the reaction of methylene blue and ceric sulfate is 2.3×10^5 while the half time measured was as long as 0.04 second. On the other hand the value of k_2 for the reaction of ceric sulfate and hydrogen peroxide is approximately 8.6×10^5 while the half time measured was 0.0004 second. In the case of the reaction of iodine with thiosulfate the extent of reaction was quite large at the shortest time measured indicating that the velocity constant (k_2) is greater than 10^6.

V. CONCLUSIONS.

1. A manual syringe drive has been found to fulfil the requirements for a high driving force causing minimum disturbance to the electro-optical system. This has permitted the attainment of a flow velocity of 25 m./sec. and a light transmission measurement of one part in 10,000.

2. One-half cc. of each reactant has been found to be sufficient for a kinetic curve when the speed of response of the photoelectric amplifier is 0.01 second.

3. For this value of fluid economy the time range of the accelerated flow method is from 0.3 to 10 milliseconds and the time range of the stopped flow method is from 30 milliseconds to 60 seconds.

4. The rate of ten rapid reactions of inorganic chemistry has been measured by these methods.

ACKNOWLEDGMENTS.

The author wishes to express his gratitude to Dr. Martin Kilpatrick for instituting this research; to Col. Edwin M. Chance for his constant aid and interest; to Dr. F. J. W. Roughton for supervision of a part of this work; to Dr. G. A. Millikan for criticizing the thesis; to Mr. W. H. Lewis for engineering and drafting aid, and to Mrs. E. J. O'Rourke for typing.

ON THE EXISTENCE AND THE MAGNITUDE OF ELECTRONIC CHARGES.

BY

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SUMMARY.

In order to quantize Dirac's classical point electron [1] we supplement Einstein's classical equation $(E/c)^2 - p^2 = b^2$ with a reciprocal classical equation $(c\Delta t)^2 - (\Delta r)^2 = a^2$ where $b = mc$ and a is Dirac's signal radius. Δt is the time saved by a light signal in various states of motion of the electron, and a/c is the rest time saved. Our former efforts [2] of obtaining an integral equation for the probability amplitude have been rectified by Born.[3] There is no solution of the integral equation, however, unless advanced and retarded phases are introduced simultaneously, along with Dirac's advanced and retarded potentials. We have obtained a transcendental equation for the eigen-value $\mu = \alpha\gamma$ where α is the Sommerfeld fine-structure constant, and γ is the numerical factor in Dirac's signal radius $a = \gamma e^2/mc^2$. The smallest eigen-value is $\mu = 0.0299$. That is, $ab = \hbar\mu = h/210$.

1. CLASSICAL THEORY OF THE POINT ELECTRON.

The Lorentz-Einstein theory ascribes the rest mass of an electric particle to the Coulomb potential of its charge cloud. Quantum theory, when considering the charge cloud as a probability cloud in order to avoid its explosive tendency, cannot overlook the fact that a small radius in space implies a large range in momentum space with energies of *motion* that would be about 100 times as large as the energy of the *rest* mass. Furthermore, since particles can have a mass without having a charge, the electrostatic theory of the mass

[1] P. A. M. Dirac, *Proc. Roy. Soc.*, **A167**, 148, 1938.
[2] A. Landé, *Phys. Rev.*, **56**, 482, 1939. JOURN. FRANK. INST., **228**, 459, 1939.
[3] M. Born, *Proc. Roy. Soc. Edinburgh*, **49**, 219, 1939.

cannot be maintained any more. For these reasons *Dirac* has reexamined the problem of the classical point electron. His chief result was that the usual singularities in the field of a point charge can be avoided if one considers the point charge as subject to the *difference* of the advanced and retarded potential produced by its own past and future path. Without resorting to a finite radius of the particle, an electronic "radius" re-appears in Dirac's theory in a quite new fashion. If a short light signal is sent toward the electron then the latter reacts already a long (infinite) time before the light signal could normally arrive at the charged point. The time saved by the bulk of the signal, as compared with a normal light signal, is $\tau = a/c$ where a may be called the "signal radius" of the particle. It is hard to obtain an exact definition of the magnitude of a. In Dirac's theory the reaction of the electron to the signal is described by functions $\exp(r/r_0)$ with $r_0 = 2e^2/3mc^2$. Therefore one may put $a = 2r_0$ or $a = r_0$ depending on whether one ascribes the time saved by the signal to the receiving electron alone or to the transmitting electron as well. According to another customary definition of the "width" of the signal one might take the value of the signal radius 2π times as large. In view of this indefiniteness we write

$$a = \gamma e^2/mc^2 \tag{1}$$

with an unknown numerical factor γ of order $\frac{2}{3}$ or $2\pi\frac{2}{3}$. The signal time saved is $\Delta t = a/c$. During the time Δt the electron has travelled the distance $\Delta r = 0$. This applies to an electron at rest and an observer at rest. If both are in the same state of motion, then the respective values are $\Delta t' = a/c$ and $\Delta r' = 0$. Relativity requires $(c\Delta t)^2 - (\Delta r)^2 = (c\Delta t')^2 - (\Delta r')^2$. Thus we obtain in general

$$(c\Delta t)^2 - (\Delta r)^2 = a^2 \qquad \text{where} \qquad a = \gamma e^2/mc^2. \tag{2}$$

Various values of Δt and Δr as viewed by an observer at rest are found on the hyperboloid defined by equation (2).

The signal equation (2) is of the same form as Einstein's equation

$$(\epsilon/c)^2 - p^2 = b^2 \qquad \text{where} \qquad b = mc. \tag{3}$$

The principal feature of this equation is that it is invariant under rotations but is not invariant under translations. The energy and the momentum of a particle can be found only on the hyperboloid defined by equation (3). There can be no "reciprocity" of the ϵ, p space and the space t, r since space-time relations must be invariant under translations as well. This is the reason that an amplitude function $\chi(\epsilon, p)$ has a physical meaning, but a function $\psi(t, r)$ describing the probability amplitude of position in space-time is meaningless. On the other hand, a probability amplitude of finding various values of the intervals Δt and Δr can have a physical meaning.

The invariant volume element in the p-space of equation (3) is

$$dw_0 = p^2 dp d\phi d(\cos\theta)[1 + (p/b)^2]^{-\frac{1}{2}}, \tag{4}$$

and the invariant volume element in the Δr-space of equation (2) is

$$dv_0 = (\Delta r)^2 d(\Delta r) d\varphi d(\cos\vartheta)[1 + (\Delta r/a)^2]^{-\frac{1}{2}}. \tag{4'}$$

It is convenient to use the reduced dimensionless coördinates

$$P = p/b, \quad E = \epsilon/bc, \quad D = \Delta r/a, \quad T = c\Delta t/a. \tag{5}$$

The proper value of P for an observer accelerated along with the electron is

$$P_0 = \int_0^P dP(1 + P^2)^{-\frac{1}{2}} = \sinh^{-1} P. \tag{6}$$

Similarly we may use the abbreviation

$$D_0 = \sinh^{-1} D. \tag{6'}$$

2. QUANTIZATION OF THE POINT ELECTRON.

The quantum theory of the electric particle shall be founded on the assumption that, the more exact we measure the distance Δr of equation (2) the less exact will be our simultaneous determination of the momentum p of equation (3). That is, we consider the probability amplitudes $\chi(p)$ and $\psi(\Delta r)$ as conjugate in the sense of the quantum theory. Our first attempt [2] to use this conjugacy was put on a reasonable basis by Born [3] whose work we are going to modify again.

First, Born's integral equation is the iteration of a much simpler one. Second, it is necessary to imitate Dirac's method of the advanced and retarded potentials; otherwise the resulting equation would be meaningless.

In terms of the reduced coördinates (5) and with the abbreviation

$$\mu = ab/\hbar = \boldsymbol{\gamma}\cdot(e^2/mc^2)\cdot(mc)/\hbar = \boldsymbol{\gamma}\cdot\boldsymbol{\alpha}, \tag{7}$$

the Fourier relations between ψ and χ read

$$\psi(D, T) = (\mu/2\pi)^{\frac{1}{2}} \int \chi(P, E) \times \exp\{i\mu(P\cdot D - ET)\}dW_0, \tag{8}$$

$$\chi(P, E) = (\mu/2\pi)^{\frac{1}{2}} \int \psi(D, T) \times \exp\{-i\mu(P\cdot D - ET)\}dV_0, \tag{8'}$$

where dW_0 and dV_0 are reduced invariant elements

$$dW_0 = P^2 dP d\phi d(\cos\theta)(P^2+1)^{-\frac{1}{2}}, \tag{9}$$

$$dV_0 = D^2 dD d\varphi d(\cos\vartheta)(D^2+1)^{-\frac{1}{2}}. \tag{9'}$$

Substituting (8) in (8') one obtains with *Born* the integral equation

$$\chi(P, E) = (\mu/2\pi)^3 \iint \chi(P', E') \times \exp\{i\mu(D\cdot P - P' - T\cdot E - E')\}dW_0' dV_0 \tag{10}$$

and a similar integral equation (10') for ψ when (8') is substituted in (8). It was Born's idea that for a "particle at rest" one has to replace E by $\pm(P^2+1)^{\frac{1}{2}}$ and T by $\pm(D^2+1)^{\frac{1}{2}}$. One might think that for every sign of the square root there were a separate integral equation so as to determine four ψ functions and four χ functions. Instead, we carry the integrals over all choices of the signs simultaneously, in line with Dirac's retarded and advanced potentials. That is, we replace factors $\exp(\pm i\sqrt{\ })$ by their sum $2\cos(\sqrt{\ })$. So we write instead of (8') and (10)

$$(11)\quad \chi(P) = (\mu/2\pi)^{\frac{1}{2}} \int \psi(D') \exp(-i\mu P\cdot D') \\ 2\cos\left[\mu(P^2+1)^{\frac{1}{2}}(D'^2+1)^{\frac{1}{2}}\right] dV_0',$$

$$(12)\quad \chi(P) = (\mu/2\pi)^3 \iint \chi(P') \exp(i\mu D\cdot P - P') \\ \times 2\cos\left[\mu(P^2+1)^{\frac{1}{2}}(D^2+1)^{\frac{1}{2}}\right] \\ \times 2\cos\left[\mu(P'^2+1)^{\frac{1}{2}}(D'^2+1)^{\frac{1}{2}}\right] dW_0' dV_0,$$

and two similar equations (11′) and (12′) for $\psi(D)$. Because of the formal equivalence of P and D, the equations for $\chi(P)$ and those for $\psi(D)$ will have the same eigenvalues μ and the same normalized eigen-functions, except for the fact that the latter may be supplied with factors ± 1 or $e^{i\varphi}$ without violating their normalization. We therefore can replace $\psi(D')$ in (11) by $\pm\chi^*(D')$. Then changing the notation D' under the integral to the notation P' we obtain instead of (11)

$$(13)\quad \chi(P) = \pm(\mu/2\pi)^{\frac{1}{2}} \int \chi^*(P') \exp(-i\mu P\cdot P') \\ \times 2\cos\left[\mu(P^2+1)^{\frac{1}{2}}(P'^2+1)^{\frac{1}{2}}\right] dW_0'.$$

(12) is the iteration of the much simpler equation (13).—Supposing spherical symmetry of χ and integrating over $d\phi$ and $d(\cos\theta)$ where θ is the angle between the vectors P and P' we arrive at

$$(13')\quad \chi(P) = \pm 8\pi\left(\frac{\mu}{2\pi}\right)^{\frac{1}{2}} \int \chi(P') \frac{\sin(\mu PP')}{\mu PP'} \\ \times \cos(\mu\sqrt{P^2+1}\,\sqrt{P'^2+1}) \frac{P'^2 dP'}{\sqrt{P'^2+1}}.$$

Then introducing the *proper* reduced momentum P_0 defined by (6) (6′)

$$P = \sinh P_0, \qquad \sqrt{P^2+1} = \cosh P_0,$$

substituting

$$(14)\qquad \chi(P)\cdot P = \varphi(P_0),$$

and rearranging sines and cosines, we arrive at the integral equation

$$(15)\quad \varphi(P_0) = \pm\sqrt{\frac{2\mu}{\pi}}\int_0^\infty \varphi(P_0')[\sin(\mu\cosh(P_0+P')) - \sin(\mu\cosh(P_0-P_0'))]dP_0'.$$

3. EXACT SOLUTION.

In order to find the eigen-values and eigen-functions of (15) we try the Ritz method. After multiplying both sides by $\varphi(P_0)dP_0$ and integrating we have

$$(16)\quad 1 = \pm\sqrt{\frac{2\mu}{\pi}}\int\int \varphi(P_0)\varphi(P_0')[\sin - \sin]dP_0dP_0'.$$

Substituting the new variables

$$u = P_0 + P_0', \qquad v = P_0 - P_0', \qquad dP_0dP_0' = -\tfrac{1}{2}dudv,$$

we obtain

$$(17)\quad 1 = \pm\sqrt{\frac{2\mu}{\pi}}\int_0^\infty du\int_0^u dv\varphi\left(\frac{u+v}{2}\right)\varphi\left(\frac{u-v}{2}\right) \times[\sin(\mu\cosh u) - \sin(\mu\cosh v)].$$

In order to satisfy this equation we use a trial function with one maximum only:

$$(18)\qquad \varphi(P_0) = CP_0\exp(-AP_0^2).$$

We consider the limit $A = 0$ where

$$(19)\quad \varphi(P_0) = CP_0 \qquad \text{and} \qquad 4\pi\varphi^2dP_0 = C^2 4\pi P_0^2 dP_0.$$

This is a *constant probability density in the proper space* for an observer who considers $4\pi P_0^2dP_0$ as his volume element. For an observer at rest the density amplitude (14) is

$$(19')\quad \chi(P) = \varphi(P_0)/P_0 = CP_0/P = (C\sinh^{-1}P)/P$$

with a maximum at $P = 0$ and a Gaussian-like decrease for larger values of P. When the trial function (18) is substituted in (17) the latter after some rearrangements reduces to

$$1 = \pm\sqrt{\frac{2\mu}{\pi}}2\cdot(-1)\int_0^\infty \sin(\mu\cosh u)du = \mp\sqrt{2\pi\mu}J_0(\mu)$$

where J_0 is the well known Bessel function. The last equation may be written

$$1 = 2\pi\mu\cdot[J_0(\mu)]^2. \tag{20}$$

This is a transcendental equation for the smallest eigenvalue μ of the equation (17). The smallest solution of (20) is

$$\mu = 0.157\cdots, \tag{20'}$$

close to $1/2\pi$. But there are larger solutions $\mu \sim 1.8$, $\mu \sim 3$ etc. Substitution proves that our trial function (19) which solves the Ritz equation (17) is already the exact ground solution of the equation (15). However, when we replaced the factor $\exp(\pm i\sqrt{\ })$ by 2 cos, we did so under the assumption that $\chi(P, \sqrt{P^2+1}) = \chi(P, -\sqrt{P^2+1})$. If however $\chi(P, \sqrt{P^2+1}) = -\chi(P, -\sqrt{P^2+1})$ then the integration over both hyperboloids amounts to replacing the factor $\exp(\pm i\sqrt{\ })$ by $2i$ sin. (This is in close analogy to Dirac's *difference* of advanced and retarded potentials.) We then have to replace $\psi(D')$ in (11) by $\pm i\chi(D')$. As a consequence, the integrand in (15) now becomes a difference of two *cosines* rather than two sines. The new integral equation (15) is again solved by the eigenfunction (19) (19'), but μ is now determined by the transcendental equation

$$1 = 2\pi\mu[Y_0(\mu)]^2 \tag{21}$$

whose smallest solution is

$$\mu = 0.0299. \tag{21'}$$

Although this eigenvalue is still larger than $1/137$ it would lead almost to the correct value of $\alpha = \mu/\gamma$ if γ were as large as $\frac{2}{3}\cdot 2\pi$ (see §1). But as long as we don't have a *classical* theory which yields a definite value of γ without ambiguity, our μ-value (21') cannot yet be used to predict α.

Prof. *L. H. Thomas* has found that higher eigenfunctions of the integral equation (15) are

$$\varphi_\nu(P_0) = \sin(\nu P_0), \text{ that is, } \chi_\nu(P_0) = \sin(\nu P_0)/\sinh P_0 \tag{22}$$

for *continuous* values of the parameter ν. The eigenvalue μ

thereby has to satisfy the transcendental equation

$$(23) \qquad 1 = \pm \sqrt{2\pi\mu}\,\frac{2}{\pi}\int_0^\infty \begin{matrix}\sin\\ \cos\end{matrix}(\mu \cosh u)\cosh(\nu u)du$$

where the sin applies to the sum, and the cos to the difference of the factors $\exp(\pm i\sqrt{\ })$. For $\nu = 0$ this is our former case (19), (20), (21). Although the spectrum of the eigenvalues μ_ν is continuous, the ground value (21′) has the preference of belonging to the only non-oscillatory eigenfunction (19′) with a maximum of $\chi(P)$ at $P = 0$. Other solutions (not eigenfunctions) of (15) are $\varphi_\nu(P_0) = \sinh(\nu P_0)$.

I am greatly indebted to Prof. Thomas for his many valuable suggestions.

THE KILLING OF BACTERIA WITH ULTRA-VIOLET LIGHT.

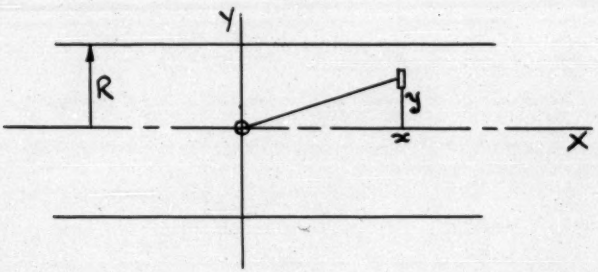
Solution by J. F. Downie Smith, Sc.D., for the case of uniform flow of air.

It is clear that, in general, uniform flow of air would not exist in an air duct; nevertheless the solution may be of interest. The approximation to actual flow where natural convection does not exist is quite good.

THE PROBLEM.

A cylindrical duct with ultra-violet light source centrally located and considered to be a point permits passage of air containing a bacteria concentration of N per cc. Assume that the velocity V across the duct is uniform; and that the law of mortality of the bacteria is given by the statement that: "The ratio of the number killed per unit time to the total number existing at the time is inversely proportional to the square of the distance of the bacteria from the light source."

FIG. 1.



Also, when $x = \infty$, at entrance (see Fig. 1), the concentration is uniform over the cross-section, but when $x = -\infty$, at exit, the concentration is not uniform. The outcoming air can be mixed, so that N_{exit} per cc. on the average may be determined.

Find $\frac{N_{exit}}{N_{entrance}}$ as a function of V, y, and k where k is a constant signifying the killing power of the lamp.

SOLUTION.

Consider small area dA of the cross-section, cylindrical in shape. According to the assumptions made,

$$\frac{dN}{Ndt} = \frac{k}{x^2 + y^2}, \tag{1}$$

$$v = \frac{dx}{dt}, \qquad \therefore \quad dt = \frac{dx}{v}, \tag{2}$$

$$\therefore \quad \frac{dN}{N} = \frac{kdt}{x^2 + y^2} = \frac{kdx}{v(x^2 + y^2)},$$

$$\therefore \quad \log N \Big]_{entrance}^{exit} = \frac{k}{v}\left[\frac{1}{y}\tan^{-1}\frac{x}{y}\right]_{x=-\infty}^{x=-\infty}$$

$$= \frac{k}{vy}\left[\tan^{-1}(-\infty) - \tan^{-1}(\infty)\right] = -\frac{\pi k}{vy},$$

$$\therefore \quad \frac{N_{exit}}{N_{entrance}} = e^{-(\pi k/vy)}. \tag{3}$$

But this is only for the small area dA. The average value of N_{exit} is obtained from

$$N_{exit}\ (\text{average}) = \frac{\int_{A=0}^{A=\pi R^2} N_{exit}\, dA}{\pi R^2}$$

$$= \frac{N_{entrance}\int_0^{\pi R^2} e^{-(\pi k/vy)}\, dA}{\pi R^2}. \tag{4}$$

Now $A = \pi y^2$ and $dA = 2\pi y dy$,

$$\therefore \quad \frac{N_{exit}\ (\text{aver.})}{N_{entrance}} = \frac{1}{\pi R^2}\int_{y=0}^{y=R} 2\pi y e^{-(\pi k/vy)}\, dy$$

$$= \frac{2}{R^2}\int_{y=0}^{y=R} y e^{-(\pi k/vy)}\, dy = P. \tag{5}$$

Let

$$z = \frac{y}{R}, \qquad \therefore \quad dz = \frac{dy}{R},$$

$$\therefore \quad P = \frac{2}{R^2}\int_{z=0}^{z=1} e^{-(\pi k/vRz)}\, Rz \cdot Rdz = 2\int_0^1 ze^{-(c/z)}\, dz,$$

where $c = \dfrac{\pi k}{VR}$, a constant.

Let

$$\frac{1}{z} = u, \qquad \therefore \quad du = -\frac{dz}{z^2} = -u^2 dz,$$

$$\therefore \quad P = -2\int_{u=\infty}^{u=1} \frac{1}{u^3} e^{-cu}\, du = 2\int_{u=1}^{u=\infty} \frac{e^{-cu}}{u^3}\, du.$$

Let

$$cu = w, \qquad \therefore \quad du = \frac{dw}{c},$$

$$\therefore \quad P = 2c^3 \int_{w=c}^{w=\infty} \frac{e^{-w}\, dw}{w^3 c} = 2c^2 \int_{w=c}^{w=\infty} \frac{e^{-w}\, dw}{w^3}.$$

See Peirce's Tables, Third Edition, No. 404, for the solution of this.

$$P = 2c^2\left[\frac{1}{2}\left\{-\frac{e^{-w}}{w^2} - \int \frac{e^{-w}dw}{w^2}\right\}\right]_c^\infty$$

$$= c^2\left[\frac{1}{c^2e^c} - \left\{-\frac{e^{-w}}{w} - \int \frac{e^{-w}\, dw}{w}\right\}\right]_c^\infty$$

$$= \frac{1}{e^c} - \frac{c}{e^c} + c^2 \int_c^\infty \frac{e^{-w}dw}{w}. \qquad (6)$$

Now $\displaystyle\int_\infty^w \frac{e^{-w}dw}{w}$ is called the "Exponential Integral" $Ei(w)$, and its value is:

$$Ei(w) = 0.577215 + \log_e w - w + \frac{w^2}{2.2!} - \frac{w^3}{3.3!}\cdots, \qquad (7)$$

$$\therefore \quad P = e^{-c}(1 - c) - 0.577215c^2$$

$$- c^2\left[\log_e c - c + \frac{c^2}{2.2!} - \frac{c^3}{3.3!}\cdots\right], \qquad (8)$$

$$\therefore \quad \frac{N_{\text{exit (average)}}}{N_{\text{entrance}}} = e^{-(\pi k/VR)}\left(1 - \frac{\pi k}{VR}\right) - 0.577215\left(\frac{\pi k}{VR}\right)^2 - \left(\frac{\pi k}{VR}\right)^2\left[\log_e\left(\frac{\pi k}{VR}\right) - \frac{\pi k}{VR} + \frac{\left(\frac{\pi k}{VR}\right)^2}{2.2!} - \frac{\left(\frac{\pi k}{VR}\right)^3}{3.3!} + \cdots\right]\cdots. \quad (9)$$

Note: The symbol ! means factorial.

If $c = 0$, $P = 1$,
If $c = 1$, $P = 0.218$ approximately,
If $c = 2$, $P = 0.106$ approximately.

MODULATION CIRCUIT THEORY.

BY

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In the usual study of electric circuit differential equations the voltages and currents are, excluding the transient solution, either independent of time as in the case of direct currents, or a periodic function of time as in the case of alternating currents. In communications systems the voltage applied to the network is either amplitude, phase or frequency modulated. A more general solution of the ordinary nth order linear differential equation is developed in the following pages. The exciting function chosen is of such a form that the solution can be easily applied to any of the methods of modulation mentioned above.

Let the differential equation to be studied be written as

$$Z(p)i = Ef(t)\epsilon^{j\omega t}, \tag{1}$$

where i = current,
$p = d/dt$,
$Z(p) = (a_n p^n + a_{n-1}p^{n-1} + a_{n-2}p^{n-2} + \cdots)$,
$f(t)$ = some time function,
E = a constant,
a_n = a constant depending upon the circuit parameters,
$\frac{\omega}{2\pi}$ = a constant frequency.

The solution to equation (1) is

$$i(t) = \underbrace{A_1\epsilon^{m_1 t} + A_2\epsilon^{m_2 t} + \cdots A_n\epsilon^{m_n t}}_{I_T} + \underbrace{\frac{1}{Z(p)}Ef(t)\epsilon^{j\omega t}}_{I_{s.s.}}, \tag{2}$$

where $I_{s.s.}$ = steady state solution,
I_T = transient solution,
A_i = constant depending upon initial conditions,
m_i = distinct root of $Z(p)$.

The solution for the steady state current can be obtained by performing the indicated operation. Let $1/Z(p) = Y(p)$; then

$$I_{s.s.} = EY(p)f(t)\epsilon^{j\omega t}. \tag{3}$$

By the shifting theorem

$$I_{s.s.} = E\epsilon^{j\omega t}Y(p + j\omega)f(t). \tag{4}$$

Expanding $Y(p + j\omega)$ about $j\omega$,

$$Y(p + j\omega) = Y(j\omega) + \sum_1^\infty \frac{1}{j^n n!}\frac{d^n Y(j\omega)}{d\omega^n}P^n. \tag{5}$$

Thus

$$I_{s.s.} = E\epsilon^{j\omega t}\left\{ Y(j\omega) + \sum_1^\infty \frac{1}{j^n n!}\frac{d^n Y(j\omega)}{d\omega^n}P^n \right\} f(t). \tag{6}$$

Whence

$$I_{s.s.} = E\epsilon^{j\omega t}\left\{ Y(j\omega)f(t) + \sum_1^\infty \frac{1}{j^n n!}\frac{d^n Y(j\omega)}{d\omega^n}f^n(t) \right\}. \tag{7}$$

Equation (2) can be now written in its final form as

$$i(t) = A_1\epsilon^{m_1 t} + A_2\epsilon^{m_2 t} + \cdots A_n\epsilon^{m_n t} + E\epsilon^{j\omega t}\left\{ Y(j\omega)f(t) + \sum_1^\infty \frac{1}{j^n n!}\frac{d^n Y(j\omega)}{d\omega^n}f^n(t) \right\}. \tag{8}$$

For practical purposes we need only consider the steady state solution which is given by equation (7).

When amplitude modulation [1] is to be considered the type of exciting function is

$$e_a = E(1 + m_a \sin \lambda t)\epsilon^{j\omega_0 t}, \tag{9}$$

where $\lambda/2\pi$ = modulating frequency,
$100m_a$ = per cent modulation,
$\omega_0/2\pi$ = carrier frequency.

[1] Roder, H., "Amplitude, Phase and Frequency Modulation," *Proc. I. R. E.*, **19**, pp. 2145, Dec., 1931.

Thus in amplitude modulation systems

$$f(t) = (1 + m_a \sin \lambda t). \tag{10}$$

When (10) is substituted in equation (8) the generalized network solution for amplitude modulation systems results.

Equation (8) can be somewhat simplified for phase and frequency modulation systems. For if we let

$$f(t) = \epsilon^{j\phi(t)}, \tag{11}$$

then we can write

$$\begin{aligned} I_{s.s.} &= E\epsilon^{j(\omega t+\phi(t))}\left\{ Y(j\omega) + \sum_1^\infty \frac{1}{j^n n!}\frac{d^n Y(j\omega)}{d\omega^n}\frac{d^n}{dt}\epsilon^{j\phi(t)} \right\} \\ &= E\epsilon^{j(\omega t+\phi(t))}\left\{ Y(j\omega) + \frac{dY(j\omega)}{d\omega}\phi'(t) \right. \\ &\quad + \frac{1}{2!}\frac{d^2Y(j\omega)}{d\omega^2}\left[\phi'(t) - j\frac{d}{dt}\right]\phi'(t) \\ &\quad + \frac{1}{3!}\frac{d^3Y(j\omega)}{d\omega^2}\left[\phi'(t) - j\frac{d}{dt}\right] \\ &\qquad \left. \times\left[\phi'(t) - j\frac{d}{dt}\right]\phi'(t) + \cdots \right\}, \end{aligned}$$

where

$$\phi'(t) = \frac{d\phi}{dt},$$

$$I_{s.s.} = E\epsilon^{j(\omega t+\phi(t))}\left\{ Y(j\omega) + \sum_1^\infty \frac{1}{n!}\frac{d^n Y(j\omega)}{d\omega^n} M_n(t) \right\}, \tag{12}$$

where

$$M_n(t) = \left[\phi'(t) - j\frac{d}{dt}\right]^{n-1}\phi'(t) \text{ symbolically.}$$

As a practical example let us apply equation (12) to the case of frequency modulation. Here

$$\begin{aligned} e_{f.m.} &= E \sin(\omega_0 t + m_f \sin \lambda t) \\ &= E\epsilon^{j\omega_0 t}\cdot\epsilon^{jm_f \sin \lambda t} \\ &= E\epsilon^{j\omega_0 t}\cdot\epsilon^{j\int u\,dt}, \end{aligned} \tag{13}$$

where

$$m_f = \Delta\omega/\lambda,$$
$$\Delta\omega = \text{frequency deviation},$$
$$u = \Delta\omega \cos \lambda t.$$

Now

$$\epsilon^{j\phi(t)} = \epsilon^{j\int u\,dt}$$

and

$$\phi(t) = \int u dt, \tag{14a}$$
$$\phi'(t) = u. \tag{14b}$$

Thus substituting equations (14a) and (14b) in (12) we get

$$I_{\substack{s.s.\\F.M.}} = E\epsilon^{j(\omega_0 t+\int u\,dt)} \left\{ Y(j\omega) + \sum_1^\infty \frac{1}{n!} \frac{d^n Y(j\omega)}{d\omega^n} M_{\substack{n\\F.M.}}(t) \right\}, \tag{13}$$

where

$$M_{\substack{n\\F.M.}}(t) = \left[u(t) - j\frac{d}{dt} \right]^{n-1} u(t) \text{ symbolically.}$$

Equation (13) has been derived by Carson and Fry [2] with the Fourier and Duhammels integrals.

CONCLUSIONS.

The method of ordinary differential equations has been demonstrated as a simple yet powerful tool in dealing with the complex circuit phenomena of either amplitude, phase or frequency modulation.

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[2] Carson, J. R., and Fry, T. C., "Variable Frequency Electric Circuit Theory," *B. S. T. J.*, **16**, No. 4, pp. 513, Oct. 1937.

COMMITTEE ON SCIENCE AND THE ARTS.

Abstract of Report, Vitamin B_1.

HALL OF THE FRANKLIN INSTITUTE,
FEBRUARY 14, 1940.

Report No. 3041

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts investigating the work of Robert R. Williams* on Vitamin B_1 reports as follows:

The word vitamin originally was a vague and comprehensive term applied to a dietary factor whose absence gave rise to certain deficiency diseases. Soon it was recognized that at least two such factors exist, the one characterized by solubility in fat, the other by solubility in water. Then evidence accumulated that several fat-soluble and several water-soluble vitamins exist. Those soluble in fat include:

Vitamins A and A_1 which are derivatives of carotene and prevent xerophthalmia.

Vitamins D_1, D_2 and D_3 which are complex polycyclic sterols and prevent rickets.

Vitamin E which is alpha tocopherol and is concerned in the prevention of sterility.

Vitamins K_1 and K_2, carbohydrate derivatives of 1 : 4 naphtho-quinone.

The vitamins soluble in water were first differentiated into vitamin B and vitamin C, the latter is ascorbic acid or cevitamic acid and prevents scurvy. The original vitamin B has been found to be a complex in which have been recognized the following:

Vitamin B_1 (vitamin F) which is thiamine and prevents beri-beri in man and polyneuritis in birds.

Vitamin B_2 (vitamin G) which is riboflavin and is required for normal growth and the prevention of cheilosis.

Vitamins B_3, B_4 and B_5 which are known chiefly by their influence on the body weight and health of rats and pigeons.

Vitamin B_6 (vitamin H) which is adermin, a complex pyridine derivative and prevents rat pellagra.

Vitamin P-P which is nicotinic acid and is a factor, if not the factor, in the prevention of pellagra.

Filtrate factor which is pantothenic acid and prevents a characteristic dermatitis of chickens.

Robert R. Williams became a chemist in the Philippine Civil Service in 1909 at the age of twenty-three years. He was soon assigned to studies on the chemical aspects of human beri-beri in collaboration with the Medical Corps of the United States Army. These studies have been continued by him in the Philippines, in the Bureau of Chemistry of the United States Department of Agriculture, and, since 1918, independently. He has been associated as a research chemist with the Western Electric Company (1919–1924), and with the Bell Telephone Laboratories as their chemical director (since 1925). He has also been a research associate of

* Dr. Williams addressed the Stated Meeting of the Institute on February 17, 1937, on "The Quest of Vitamin B_1." See J. F. I., Vol. 224, p. 541, November 1937.

the Carnegie Institution of Washington and of the Teachers College, Columbia University, since 1923.

His work on beriberi and its associated vitamin B_1 began about 1910 and culminated in 1934 in the development of a process whereby the vitamin was isolated from rice polish as a crystalline compound; the yield, 5 grams per ton of rice polish, was a yield of 25 per cent. of the vitamin actually present in the raw material. This process, in brief, depended upon extraction of the polish with water at a pH of 4.5 with toluene as a bactericide adsorption of the vitamin on fuller's earth, its elution by means of quinine sulphate, and an elaborate purification of the resulting solution. The process was covered by United States Patent 2,049,988, granted August 4, 1936, to Robert R. Williams and Robert E. Waterman, assignors to Research Foundation for "Process for Obtaining Vitamins."

The quantity of vitamin B_1 obtained by this process permitted minute study of it chemically and physically.

The report of this process in 1934 was the first of a series of eighteen papers embodying researches of Williams and his collaborators on the vitamin, its structure and its synthesis, and, incidentally, its action on man and experimental animals.

The elementary composition of the hydrochloride of the pure vitamin was first ascertained. It was next established that, when the crystalline vitamin was dissolved in 2.6 normal sodium sulphite solution containing sufficient excess of sulphurous acid to produce a pH of 4.8–5.0, and the solution was permitted to stand overnight at room temperature, the vitamin was cleaved into two segments. Further study revealed that one of these segments was 2-methyl-5-hydroxymethyl-6-amino-pyrimidine, and the other segment 4-methyl-5-beta-hydroxyethyl thiazole. By union of these two segments, the vitamin has been synthesized for the first time, and produced in quantity. The synthetic crystalline vitamin has the same effect upon polyneuritis and growth as is possessed by natural sources of the vitamin.

Two additional United States patents were issued to Robert R. Williams, assignor to Research Corporation, No. 2,134,015 on October 25, 1938 for "Thiazole Compounds" and No. 2,153,016 on April 4, 1939 for "Pyrimidine Compounds."

It may be mentioned that the Research Corporation applies its profits for the support of research and kindred public objects.

In collaboration with Tom D. Spies, M.D., Williams has published a book entitled "Vitamin B_1 (Thiamin) and Its Use in Medicine," New York, 1938.

In 1935 Ottawa University conferred upon Williams the honorary degree of Doctor of Science.

The appended bibliography lists the publications, during the period 1934–1938, embodying the researches on vitamin B_1 conducted by Williams or under his supervision.

In consideration of his researches upon vitamin B_1, including its isolation in the pure state in quantity sufficient for further chemical study, the identification of its segments, and its synthesis in quantity, your Sub-Committee recommends the award of an Elliott Cresson Medal to

ROBERT R. WILLIAMS, Sc.D.,
of New York City, N. Y.

(Committee of Investigation: JOSEPH S. HEPBURN, *Chairman*, THOMAS D. COPE, GEORGE S. CRAMPTON, W. H. FULWEILER, HIRAM S. LUKENS.)

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Inert Gas Application: Three Case Studies.—H. W. SMITH, JR., of the American Gas Association, states in *Industrial Gas*, Vol. XVIII, No. 9, that within the past two years, paint and varnish men have watched with keen interest a rapidly widening application within their industry of a new type of apparatus: that of the inert gas generator. These devices burn carefully controlled mixtures of regular city gas and air within closed chambers, purify and scrub the products of combustion, and thus deliver (or generate) at very low cost large volumes of absolutely inert gases which neither burn nor support combustion but which are valuable in the paint and varnish plant for (1) "blowing" synthetics during cooking; (2) excluding air (oxygen) from contact with heated batches of varnish or oil; (3) eliminating troublesome skinning of paint or varnish or oil; (4) preventing the gradual accumulation of gummy layers of oxidized paints and varnishes on the inside walls of large storage tanks; (5) extinguishing and preventing fires; (6) minimizing skinning in the can or reducing oxidation during grinding or homogenizing. At the Cook Paint and Varnish Company, Detroit, a vertical tower type of inert gas generator is used. The current cost of providing atmosphere protection over varnish kettles is only approximately one-fifth of the cost previously sustained to support bottled carbon dioxide to these same operations. Fully automatic machinery has provided similar inert gases to the plant of the Glidden Paint and Varnish Company in Cleveland for some 15 months. Here it is stated that inert gas is better than carbon dioxide in that it permits shorter cooling times through more vigorous agitation and can be used more freely throughout the plant because of its lower cost. At the third plant, the Sherwin-Williams Company of Cleveland, the generating unit was in operation to supply inert gas for agitating and blanketing roughly one-third of the plant's varnish production during cooking. Also, the inert atmosphere gas was being used in three 1250 gal. storage tanks which contained particularly fast-skinning products.

R. H. O.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

SAFETY RULES FOR INSTALLATION AND MAINTENANCE OF ELECTRIC UTILIZATION EQUIPMENT.

Handbook H33, which is now available in printed form, consists of part 3 of the National Electrical Safety Code dealing with utilization equipment and the grounding rules contained in section 9. The detailed rules deal with conductors and protective devices used in the interior wiring of buildings and also with the control equipment, including switchboards and panel boards. Separate sections are devoted to various applications, such as motors and motor-driven machinery, electric furnaces, lighting fixtures, portable appliances, etc. A section is also concluded on telephone and other communication apparatus. The requirements for grounding and the methods of making grounding connections are dealt with in detail.

Copies of H33 are sold by the Superintendent of Documents, Government Printing Office, Washington, D. C., at 15 cents each.

NEW RATE OF FLOW METER FOR VARIABLE DISCHARGES.

A new rate of flow meter recently completed in the Bureau's shops and installed in the hydraulics laboratory makes it possible to measure accurately the variable discharge rates characteristic of certain types of plumbing fixtures.

The function of this device is to catch the discharge water from a plumbing fixture in several successive compartments, the motion of which beneath the discharge nozzle is accurately timed. To accomplish this, the meter is built with a rotating annular container or bucket, 50½ inches in outside diameter, 2 feet high, and divided into 60 equal segmented compartments. This container is mounted on a vertical shaft which

* Communicated by the Director.

is driven, through a variable speed transmission, by an electric motor. Any speed up to 6 r.p.m. can be secured.

In making a test, the total time consumed in a discharge is noted, and the speed of the meter is so adjusted that a trifle less than one complete revolution is accomplished in this time. Then, as the plumbing fixture discharges, the annular container rotates and catches an amount of water in each compartment exactly proportional to the rate of discharge during the very brief interval of time that the compartment was under the discharge nozzle.

The water in the compartments is then drawn off through stopcocks into glass graduates where the volume is accurately determined. These results, when plotted against time, give a curve which shows every variation in the discharge of the fixture.

At present, the meter is being used in the cooperative investigation of flows in plumbing systems, sponsored by the Plumbing Fixture Manufacturers Research Associateship and the Bureau. Already some unsuspected peculiarities in discharge rates have been discovered.

SIMPLIFIED CURL TESTER FOR PAPER.

The curling of paper often causes trouble in printing processes and in other industrial uses of paper. Curling is caused by a differential expansion of the two sides of the sheet when the atmospheric conditions change. An instrument, known as the curl sizing tester, designed by F. T. Carson and Vernon Worthington has been used for some time at the Bureau to measure the rate of penetration of water and the angle through which a paper curls when wet on one side. Recently, this apparatus has been simplified in its application to the latter purpose. The testing device is an aluminum float provided with a wetting aperture, a specimen holder, and a scale laid off in degrees. The maximum angle of curl for a given width of aperture affords a measure of the relative curling tendency. Such data correlate satisfactorily with the likelihood of curling trouble that one may expect in the use of various papers.

REDETERMINATION OF MUNSON-WALKER REDUCING SUGAR VALUES.

Lester D. Hammond has determined reducing sugar values for a new mixture of sucrose and invert sugar containing 0.3 g. of total sugar, in order that a sample of a new sugar product of a high content of invert sugar can be weighed directly in such manner as to fall within the limits of the method of Munson and Walker. The conditions of this method were rigorously followed, but the copper was determined electrolytically instead of weighing it directly as cuprous oxide. Also, the Munson-Walker values were redetermined, and corresponding values for levulose were determined. An extensive table of reducing sugar values for dextrose, levulose, invert sugar, and for sucrose and invert sugar mixtures containing 0.3 g., 0.4 g., and 2.0 g. of total sugar has been computed.

The complete report of this redetermination will be published as RP1301 in the May number of the *Journal of Research*.

ISOLATION OF HYDROCARBONS FROM PETROLEUM.

The aromatic-free fraction of a midcontinent petroleum boiling between 90° and 92° C. was substantially resolved into its constituent hydrocarbons, and the work is reported in RP1296 by Augustus R. Glascow, Jr., in the May *Journal of Research*. Alternation of atmospheric distillation and azeotropic distillation with methyl alcohol separated the material boiling between 90° and 91.2° C. into a concentrate of 2-methylhexane and a naphthenic concentrate. From the naphthenic concentrate, *trans*-1, 3-dimethylcyclopentane was isolated by crystallization from liquid ethane. A similar procedure separated the material boiling between 91.2° and 92° C. into a naphthenic and a paraffinic concentrate. From the naphthenic concentrate, *trans*-1, 2-dimethylcyclopentane was isolated by crystallization from liquid propane plus methane. From the paraffinic concentrate, 3-methylhexane was obtained in the residue from distillations at reduced pressure (215 mm. Hg). The physical properties of the isolated hydrocarbons and an estimate of their relative amounts in the original petroleum are given.

PERFORMANCE TESTS OF FLOOR COVERINGS.

Building Materials and Structures Report BMS43, released a short time ago, reports the latest performance tests of floor coverings, suitable for low-cost housing projects. It supplements BMS34.

The floor coverings included battleship linoleum, rubber in sheet and tile form, felt-base coverings with various wearing surfaces, three monolithic floors, and a number of asphalt tiles. Lignin pastes, resinous cements, latex adhesives, rubber cements, cut-back asphalt, and asphalt emulsions were used as bonding agents.

Important factors considered are: Condition of subfloor as to evenness, cleanliness, and rigidity; exposure to which the installation is subjected, especially with respect to moisture, concentrated loads, and traffic; durability in relation to cost; and ease or cost of removal and replacement.

Copies of BMS43 are obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., at 10 cents each.

STRENGTH OF REFRACTORY MORTARS.

Air-setting refractory mortars are used to advantage in installations where temperatures are not sufficiently great to cause bonding of firebrick if ground fire clay or high temperature cements are used. Such mortars are marketed either wet or dry. There is some preference for the dry material in freezing climates or in cases where small quantities of mortar are required at periodic intervals and the mortar is mixed as needed.

A study has been completed at the Bureau which included the testing of a fire clay from Ohio and one from Pennsylvania and six proprietary brands of air-setting mortars, with the following results: Beginning with mixtures too stiff for trowelling of the Ohio clay alone, the Ohio clay and grog, and the Ohio clay, grog, and silicate of soda in solution, it was found that the dry strength first increased with the addition of water, then decreased. At maximum strength, however, the mixtures were far too stiff for trowelling purposes. The mix containing the silicate of soda showed con-

siderable increase in strength as length of time of mixing was increased and water content remained unchanged. The Pennsylvania fire clay, which had a dry strength of about 100 lb./in.^{2}, when mixed with 12.5 per cent. of silicate of soda of the dry type and of a soda-silica ratio of 1 : 2, developed a strength of about 2500 lb./in.^{2}. When silicate of soda of a soda-silica ratio of 1 : 3.2 was substituted, the same increase in strength took place. With this silicate of soda, however, the strength of mixes containing as much as 7.5 per cent. of the silicate remained low, which was opposite to the effect obtained with the silicate of higher soda-silica ratio. For equal percentages of the silicate, the pyrometric cone equivalents of the mixes containing the silicate of the 1 : 2 soda-silica ratio were considerably below those containing the silicate of 1 : 3.2 soda-silica ratio.

The results of strength tests made after mixing mortars 1/2, 2, 5, 10, 15, and 20 hours and maintaining the water about constant indicated that air-setting mortars may show the following differences: 1. Increase in strength with mixing time up to 5 hours and decrease thereafter; 2. Greatest strength after 1/2 hour, but the decrease thereafter is comparatively slight; 3. Lowest after 2 hours of mixing and greatest strength after 10 hours.

It was noted that the mortars stored in sealed sheet iron drums retained their strengths after many months in storage, whereas those stored in burlap sacks lined with moistureproof paper decreased greatly in strength. Such loss in strength was accompanied by the increase of carbonates.

The American Association of Industrial Physicians and Surgeons will hold their Twenty-Fifth Annual Meeting together with the American Industrial Hygiene Association which will hold its first Annual Meeting at the Hotel Pennsylvania, New York City, on June 4, 5, 6, and 7, 1940. This four-day Convention will be intensively devoted to the problems of industrial health in all of their various medical, technical, and hygienic phases, with particular stress on prevention and control of occupational hazards. Important programs have been prepared, and technical and scientific exhibits will be a feature of the Convention. The Dinner on Thursday evening, June 6th, will be the occasion of the presentation of the Wm. S. Knudsen award for the year of 1939–40. All who have an interest in these phases of industrial health including industrial hygienists, safety engineers, chemists, plant engineers and personnel managers, are urged to attend as this program will have unusual value to all these groups.

Most Powerful Testing Machine Goes into Research Service.—(*Engineering News Record*, Vol. 124, No. 11.) Scientific and engineering notables in attendance at the inauguration recently of a 1500 ton Emery testing machine at the New Kensington (Pa.) research laboratory of the Aluminum Corp. of America saw it squeeze a 7×7 in. billet down to 2×2 in. size as a demonstration of its research possibilities. While the machine can crack eggs and break the crystal of a watch without harming case or works, such performances will not be included in its practical services. Its principal use, aside from determining the strength of full size structural members, will be for investigating pressures and other factors of pressforging and extrusion. The machine stands 40 ft. 4 in. high, 15 ft. 4 in. of this being below test floor level. Its maximum frame gaps are $7\frac{1}{2} \times 15\frac{1}{2}$ ft. for compression and $7\frac{1}{2} \times 12\frac{1}{2}$ ft. for tension, with corresponding loading capacities of 3,000,000 lb. and 1,000,000 lb. Built by Baldwin-Southwark Co., it has a hydraulic press to apply the load and a hydraulic capsule to meausre it. Pressure is provided by two pumps driven by 25 and 300 hp. motors respectively; the larger unit is able to give the traveling head of the machine a speed of 36 in. per minute under maximum load. While two Emery machines have larger load capacity—the University of California machine with compression and tension capacities of 4,000,000 and 3,000,000 lb., respectively, and the University of Illinois machine with 3,000,000 lb. capacity in both—the high head speed of the New Kensington machine makes it the most powerful testing machine in existence.

R. H. O.

THE FRANKLIN INSTITUTE

MEDAL DAY MEETING,

WEDNESDAY, MAY 15, 1940.

The annual Medal Day meeting was called to order at three-thirty o'clock, P.M., by the President, Mr. Philip C. Staples.

The President called upon the Secretary to report any business, inasmuch as this was the regular monthly meeting of the Institute.

Dr. Allen stated that during the year the Institute has been guiding its members and friends, through a series, of lectures, back to Benjamin Franklin, his calm reasoning, his homely virtues, and pointed out how much these are needed in the world today. In mentioning the award of medals, Dr. Allen stated it was notable that all the men to be honored today were Americans; that it is unusual that no foreigner was signalled out by the Committee on Science and the Arts, due largely to the fact that scientists in European countries have found their talents turned to other things rather than the peaceful pursuit of scientific research.

In commenting on Dr. Allen's report, Dr. Staples said: "The Secretary seems to be disturbed. You men are gathered here today because of your distinction in the field of science and we are proud that we have so many Americans of genius.

"I suppose the medalists would like to know something of the Committee which recommends the awards. The Committee on Science and the Arts has charge of selecting men, both from here and abroad, to be the recipients of our medals. The Committee, made up of members of The Franklin Institute, meets continuously. The Committee combs the field of distinguished men, it considers men of all nations, for the award of medals. It's research in the world of science is complete.

"It is a source of great pride to The Franklin Institute that men of comparative obscurity have often been selected by the Committee to receive our awards. The Institute has many times been the first to recognize men who have gone on. It would seem that recognition from The Franklin Institute has led to signal honors from other organizations.

"You will see from the programme the gentlemen who have been recommended by the Committee on Science and the Arts to receive awards this year. Our Committee has proved its competency through one hundred years. It has been recommending awards since 1848. It is possible that you gentlemen who are about to be honored today do not realize the distinction, the world renown, of the scientists who have preceded you. I should like to read a few of the names:" (Here Mr. Staples read from the records the names of outstanding medalists of other days.)

Then Mr. Staples continued: "I hope these gentlemen who still survive are as proud of being on this list as we are of the list. You are in the company, gentlemen, of very distinguished predecessors, and you add to the distinction of the list!"

The meeting then proceeded to the presentation of the several awards recommended by the Committee on Science and the Arts:

	Sponsor
Presentation of Certificate of Merit	
GEORGE H. ERNSBARGER, Honolulu, T. H., and FRANK LEE MCCARTY, Ogden, Utah.	Mr. C. D. Galloway
Presentation of Longstreth Medals	
LEOPOLD GODOWSKY, JR., and LEOPOLD DAMROSCH MANNES, Eastman Kodak Company, Rochester, New York.	Dr. George S. Crampton
GAMES SLAYTER, Vice-President, Owens-Corning Fiberglas Corporation, Newark, Ohio.	Mr. Warren P. Valentine
RICHARD L. TEMPLIN, Chief Engineer of Tests, Aluminum Company of America, New Kensington, Pennsylvania.	Mr. Walter H. Fulweiler
MAXWELL MAYHEW UPSON, D. Eng., President, Raymond Concrete Pile Company, New York City, New York.	Mr. John A. Vogleson
Presentation of Wetherill Medals	
LAURENS HAMMOND, President, Hammond Instrument Company, Chicago, Illinois.	Dr. Charles B. Bazzoni
EDWARD ERNST KLEINSCHMIDT, President, Kleinschmidt Laboratories, Incorporated, Highland Park, Illinois, and HOWARD L. KRUM, Beverly Hills, California.	Mr. Charles E. Bonine
Presentation of Henderson Medal	
WILLIAM E. WOODARD, Vice-President in Charge of Design, Lima Locomotive Works, Incorporated, New York City, New York.	Dr. Rupen Eksergian

	Sponsor
Presentation of Levy Medal	
CHARLES ROSENBLUM, Ph.D., Instructor in Physical Chemistry, Princeton University, and JOHN F. FLAGG, Ph.D., Instructor in Chemistry, University of Rochester.	Mr. Lionel F. Levy
Presentation of Cresson Medals	
FREDERICK M. BECKET, Sc.D., LL.D., Consultant, Union Carbide and Carbon Corporation, New York City, New York.	Dr. G. H. Clamer
ROBERT R. WILLIAMS, D.Sc., Chemical Director, Bell Telephone Laboratories, Incorporated, New York City, New York.	Dr. Joseph S. Hepburn
Presentation of the Franklin Medal and Certificate of Honorary Membership	
ARTHUR HOLLY COMPTON, Ph.D., Sc.D., LL.D., Ryerson Physical Laboratory, University of Chicago. Represented by his brother, Karl Compton, Ph.D., Sc.D., LL.D., President, Massachusetts Institute of Technology.	Dr. Frederic Palmer, Jr.
LEO HENDRIK BAEKELAND, D.Nat.Sc., D.Ch., D.Sc., LL.D., President (Retired), Bakelite Corporation, New York City, New York.	Dr. Frederic Palmer, Jr.

Papers.

"What We Have Learned From Scattered X-Rays"

by

DR. ARTHUR H. COMPTON

"Career of a Research Chemist"

by

DR. LEO H. BAEKELAND

Adjourned.

HENRY BUTLER ALLEN,
Secretary.

(An extended account of the proceedings of Medal Day will be published in an early issue of the JOURNAL.)

LIBRARY NOTES.

The committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is forty cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 902 readers made use of the facilities during the twenty-six days of April.

RECENT ADDITIONS.

AERONAUTICS.

Aerosphere 1939, Including World's Aircraft Engines with Aircraft Directory. 1940.

BARRINGER, LEWIN B. Flight Without Power. 1940.

AGRICULTURE.

GERICKE, W. F. The Complete Guide to Soilless Gardening. 1940.

ARCHITECTURE AND BUILDING.

FITZMAURICE, R. Principles of Modern Building. Volume I. Great Britain, Department of Scientific and Industrial Research. 1939.

STANGLE, WILLIAM HULL. An Air-Conditioning Primer. First Edition. 1940.

ASTRONOMY.

RUSSELL, HENRY NORRIS, AND CHARLOTTE E. MOORE. The Masses of the Stars. 1940.

BIOLOGY AND BIOCHEMISTRY.

SHOHL, ALFRED T. Mineral Metabolism. 1939.

CHEMISTRY AND CHEMICAL TECHNOLOGY.

American Gas Association. Proceedings. Twenty-first Annual Convention. 1939.

CONWAY, EDWARD J. Micro-Diffusion Analysis and Volumetric Error. 1939.

CRUMPLER, THOMAS B., AND JOHN H. YOE. Chemical Computations and Errors. 1940.

ELLIS, CARLETON. Printing Inks. 1940.

LATIMER, WENDELL M., AND JOEL H. HILDEBRAND. Reference Book of Inorganic Chemistry. Revised Edition. 1940.

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SVEDBERG, THE, AND K. O. PEDERSEN. Die Ultrazentrifuge. 1940.

ELECTRICITY AND ELECTRICAL ENGINEERING.

Edison Electric Institute. Electrical Metermen's Handbook. Fifth Edition. 1940.

LAPORTE, MARCEL. Décharge Électrique dans les Gaz. 1939.

ENGINEERING.

American Society for Testing Materials. Proceedings of the Forty-Second Annual Meeting, 1939. Volume 39. 1940.

SYPHERD, W. O., AND SHARON BROWN. The Engineer's Manual of English. 1933.

GEOLOGY AND GEOPHYSICS.

BALL, MAX W. This Fascinating Oil Business. 1940.

CAGNIARD, L. Réflexion et Réfraction des Ondes Séismiques Progressives. 1939.

LUMSDEN, J. Magnesium, Magnesite, and Dolomite. Great Britain. Imperial Institute. Mineral Resources Department. 1939.

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FICKLEN, JOSEPH B. Manual of Industrial Health Hazards. 1940.

MATHEMATICS.

LOVITT, WILLIAM VERNON. Elementary Theory of Equations. 1939.

MECHANICAL ENGINEERING.

FINCH, WILLIAM COLES. Watermills and Windmills. No date.

METALLURGY.

HOKE, C. M. Refining Precious Metal Wastes. 1940.

METEOROLOGY.

BOTLEY, C. M. The Air and Its Mysteries. 1940.

NAVAL ARCHITECTURE AND NAVIGATION.

Jane's Fighting Ships. 1939.

LEWIS, MICHAEL. England's Sea-Officers. 1939.

PHYSICS.

FOWLER, R. H., AND E. A. GUGGENHEIM. Statistical Thermodynamics. 1939.

GAMOW, G. Mr. Tompkins in Wonderland. 1940.

JAUNCEY, G. E. M., AND A. S. LANGSDORF. M. K. S. Units and Dimensions and a Proposed M. K. O. S. System. 1940.

LORD, EUGENE HODGDON. Experimenting at Home with the Wonders of Science. 1940.

RADLEY, J. A., AND JULIUS GRANT. Fluorescence Analysis in Ultra-Violet Light. Third Edition. 1939.

SCIENCE—HISTORY.

REASON, H. A. The Road to Modern Science. 1940.

STATISTICS.

SHEWHART, WALTER A. Statistical Method from the Viewpoint of Quality Control. 1939.

STEAM ENGINEERING.

KUHLER, OTTO, AND ROBERT S. HENRY. Portraits of the Iron Horse. 1937.

NOTES FROM THE BARTOL RESEARCH FOUNDATION.

THE INSTABILITY OF THE MESON.*

BY

MARTIN A. POMERANTZ.

Values of the proper lifetime of the meson have been deduced from a comparison of the intensity of mesons in an inclined direction under air with that in the vertical under a superposed lead shield equivalent in absorbing power to the difference between the masses of air traversed by the mesons before reaching the apparatus in the two directions (see Fig. 1).

FIG. 1.

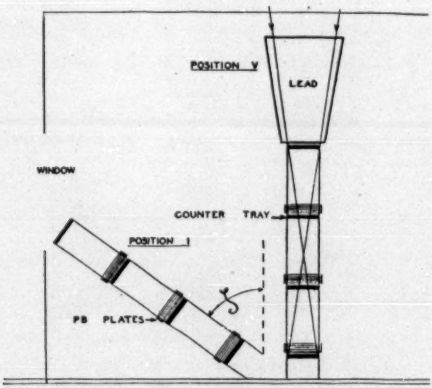


Diagram of the quadruple coincidence counter train used for obtaining the data from which the proper lifetime of the meson was determined.

The required mass of lead was calculated from the Bethe and Bloch formula. The reliability of this use of the formula has

* An abstract of an article published in full in *The Physical Review*, **57**, 3 (1940).

V. 19

been verified by an experimental determination of the relative stopping powers of water and lead. We calculate from our experimental data that the average proper lifetime of all mesons having energies exceeding 6.1×10^8 ev. upon reaching the apparatus is equal to 3.9 ± 0.3 microseconds, and the average proper lifetime of all mesons with energies exceeding 11.9×10^8 ev. upon reaching the apparatus is equal to 3.8 ± 0.4 microseconds. From the same data, the proper lifetime of only those mesons having about 9×10^8 ev. energy upon reaching the apparatus is equal to 2.6 ± 0.8 microseconds. With the theory of Euler and Heisenberg, the proper lifetime has also been calculated from measurements of the number of disintegration electrons and their secondaries in equilibrium with the mesons in air. The value obtained by this method is roughly equal to 6 microseconds.

THE CONTRIBUTIONS OF SHOWERS TO THE COINCIDENCES RECORDED AT HIGH ELEVATIONS.*

BY

T. H. JOHNSON and J. G. BARRY.

The absence of an east-west asymmetry in the cosmic radiation at very high elevations found by our balloon flights in Panama [1] was interpreted as indicating that the primary rays of the soft component consists of equal numbers of positives and negatives, a characteristic which distinguishes these rays from the primaries of the hard component since the latter are known to be almost entirely positive. On the basis of this finding we concluded that the primaries of the hard component could not be electrons but were probably protons. As we pointed out in the report of the Panama flights equal intensities from the east and west could not be otherwise interpreted unless many of the counts recorded by our coincidence counters were produced by particles whose primaries entered the atmosphere from directions other than those described by out counter train. In seeking possible causes for such deviations between the directions of the

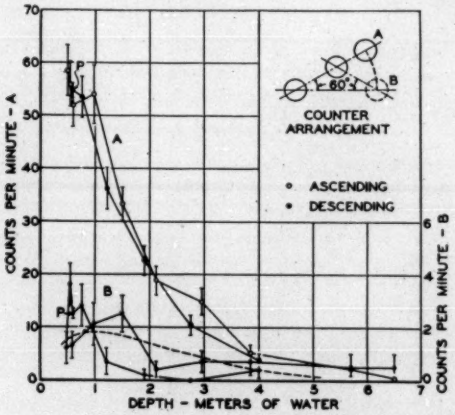
* Reprinted from *The Physical Review*, **57**, 245 (1940).

[1] T. H. Johnson and J. G. Barry, *Phys. Rev.*, **56**, 219 (1939); T. H. Johnson, *Rev. Mod. Phys.*, **11**, 208 (1939).

primary and secondary rays the two effects considered, namely, nuclear scattering and deviations of slow secondary particles in the earth's magnetic field,[2] were found inadequate to account for the observed lack of asymmetry. Recently Oppenheimer[3] has sought to revive the possibility that the mesons of the hard component are produced by primary electrons (or their photon secondaries) admitting that these may be entirely positive, and he has asked if in our measurements coincidences produced by air showers might have obscured the asymmetry of the primary rays.

In answer to Oppenheimer's suggestion we have made two flights in which the three coincidence counters were arranged alternately in line, position *A*, Fig. 1, with the principal axis

FIG. 1.



The variation of in-line, *A*, and out-of-line, *B*, coincidences with atmospheric depth. The points *PP* are based upon 45-minute averages, the other points upon 5-minute averages.

inclined 60° from the vertical, as in our Panama flights, and then, with nearly identical spacing, in the out-of-line position *B*. The contributions to the counting rates by showers from

[2] T. H. Johnson, *Phys. Rev.*, 56, 228 (1939).

[3] J. R. Oppenheimer, private communication.

the air or from the batteries beneath the counters should be the same in both arrangements, but single rays would not be recorded in the out-of-line position. Care was taken to have the spacings of the counters and their positions relative to the batteries as nearly as possible the same as in our Panama flights, and except for a small electric motor which moved one of the counters between the two positions A and B at two-minute intervals, these instruments were identical with those used in Panama.

On the first flight the counters failed when the apparatus reached the equivalent depth of 2 meters of water, but at that depth the in-line counting rate was many times the out-of-line rate. The record of the second flight was complete and the results are shown in Fig. 1 where the counting rate with each arrangement of counters is plotted against atmospheric depth. This flight ascended to an atmospheric depth equivalent to 47 cm. of water and signals were received for four and one-half hours. The upper curve plotted to the scale on the left shows the in-line counting rates based upon 5-minute averages while the lower curve plotted to the scale on the right shows the out-of-line counting rates, also based upon 5-minute averages. *At the higher elevations the air showers contribute only about five per cent. of the in-line counts and it is impossible to attribute the lack of asymmetry observed by our flights in Panama to this cause.* Thus there seems to be no escape from our conclusion that mesons are not produced by rays of the soft component but are probably produced by primary protons.

The small increase of air shower intensity with elevation is a matter of some interest although it is readily interpreted if account is taken of the lower concentration of air at the higher elevations. If showers of a given type are considered, namely, those in which a pair of particles diverges at a given angle θ, it is clear that such a shower may produce a coincidence in the out-of-line arrangement if it originates at some distance x to $x + dx$ above the counters, a distance independent of the atmospheric pressure and depending only upon the angle θ. Thus the probability that a ray will produce a shower capable of giving a coincidence varies as the amount of matter in dx, or in proportion to the atmospheric depth h.

Since the intensity of the soft component varies at depths below that of maximum intensity according to the law [4] $j_s = j_0 e^{-0.5h}$ where h is in meters of water, the variation of air shower counting rate should vary as $he^{-0.5h}$. The latter function is represented by the dotted curve in Fig. 1 and it is in fair agreement with the experimental points representing the air shower intensity.

These flights have been made with financial support from the Carnegie Institution of Washington.

FAST NEUTRON MEASUREMENTS WITH RECOIL COUNTERS.*

BY

S. A. KORFF.

For certain purposes it is convenient to have counters which respond to fast neutrons only. Proportional counters,[1] with gases other than BF_3, may be used to count recoil nuclei. A fast neutron may collide with one of the nuclei of the gas in the counter, and will then produce a recoil nucleus which will in general ionize heavily along a comparatively short range. If the counter be operated at a voltage below its threshold then the size of the pulse arriving on the central wire will be proportional to the number of ions formed in the counter by the passage of the ionizing particle. By adjusting the amplifier to discriminate against pulses below a certain size, or by adjusting the voltage applied to the counter and hence the amount of additional ionization produced by each ion as it travels toward the central wire, it is possible to count only particles producing more than a certain number of ions. In this way a counter may discriminate against pulses produced by beta- or gamma-rays. Such a counter will have a background due to the alpha-rays emitted by the natural contamination, which can easily be measured and allowed for.

The counting rate, n counts per second, of a fast neutron recoil counter will be a measure of the current $i(v)$ of fast neutrons per cm.^{2} per sec. of velocity v passing through the

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[4] L. W. Nordheim, *Phys. Rev.*, **51**, 1110 (1937).

* Reprinted from *The Physical Review*, **56**, 1241 (1939).

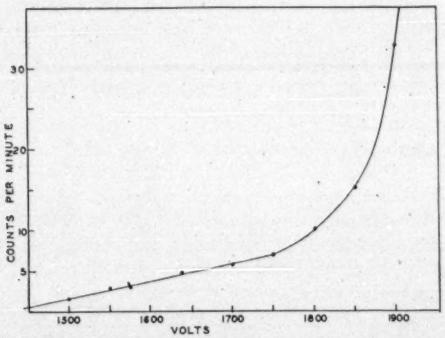
counter, as given by:

$$n = VNMp \int_{v_{min}}^{\infty} i(v)\sigma_r(v)dv, \qquad (1)$$

where N is the Loschmidt number, p is the gas pressure in the counter in atmospheres, M is the number of nuclei per molecule, V is the volume of the counter, σ_r is the cross section of the nuclei of the gas in the counter for the production of recoils of energy $E > E_{min.}$, where $E_{min.}$ is the smallest amount of energy which, if liberated as ionization in the counter, will produce a count, and $v_{min.}$ is the velocity corresponding to $E_{min.}$. This latter quantity can be determined experimentally for a given counter at a given voltage by observing the response to rays of different known ionizing powers. The above relation neglects wall effects and end corrections, which for certain cases can be shown to be unimportant.

In a specific example, Fig. 1 shows the counting rate of

FIG. 1.



Counting rate of recoil counter in presence of Ra-Be neutron source, as a function of voltage. No beta- or gamma-rays are counted below about 1770 volts.

such a counter, with a hydrogen-methane filling when operated in the presence of a Ra-Be neutron source. It will be seen that at low voltages (1450 volts) the most heavily ionizing of the recoils produces pulses just big enough to

record. As the voltage is increased the number of additional ions produced in the counter is increased, and recoils of less and less energy are counted, until at 1770 volts the largest of the pulses produced by beta-rays is big enough to be counted. At still higher voltages (1850 volts), the counting rate rises rapidly as all the beta- and gamma-rays are counted.

It will be noted that this counter has no plateau, but that the counting rate rises steadily with the voltage. This absence of plateau is due to the continuous distribution of energies of the recoiling nuclei, and is to be contrasted with the behavior of the BF_3 counters [1] in the presence of slow neutrons. The latter exhibit a plateau since the pulses produced by the alpha-particles resulting from the boron disintegration are all greater than a given size.

This type of counter has been used in studying the neutrons in the cosmic radiation. A preliminary balloon flight has been made with such a counter. The data were transmitted by short wave radio to the ground station. Interpretation of the results in terms of a neutron flux, by use of Eq. (1), is difficult, because of our lack of knowledge of the energy distribution. However, by making a simplifying assumption, a rough calculation can be made. Let us assume that protons are the only recoiling particles, and further, that σ_r is a constant and about 2×10^{-24} cm.^{2} (This corresponds [2] to 4-Mev neutrons; at lower energies σ is larger and at higher energies smaller.) The observed n was 6×10^{-3} per sec. (at 1 meter of water), V was 60 cc., MNp was 8×10^{18}, and hence i was 6.9 neutrons per cm.^{2} per sec. This may be compared with a current of 1.5 reported by v. Halban, Kowarski and Magat [3] at a lower elevation (3 m. water). It must be remembered that this estimate is very rough. Further experiments and calculations are in progress.

This work has been partly supported by the Carnegie Institution of Washington. The author is indebted to M. D. Whitaker and New York University for the loan of the neutron source, and to E. T. Clarke for assistance with the observations.

[1] S. A. Korff and W. E. Danforth, *Phys. Rev.*, **55**, 980 (1939).

[2] C. Kittel and G. Breit, *Phys. Rev.*, **56**, 747 (1939).

[3] H. v. Halban, L. Kowarski and M. Magat, *Comptes rendus*, **208**, 572 (1939).

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

Further Studies on the Bactericidal Agents Obtained from Soil Bacilli.—ELLICE MCDONALD, Director. Recently Dr. Hoogerheide of this laboratory, in his three years' work upon the encapsulation of Friedländer's bacterium, isolated from soil bacilli a substance which inhibited encapsulation and at the same time was highly bactericidal for Gram-positive microorganisms (JOURNAL OF THE FRANKLIN INSTITUTE, **229**: 677, May 1940). The beneficial and therapeutic possibilities of this substance are so far-reaching that a thorough investigation of its properties, structure and applications was necessary, and as the scope of such investigation was beyond that of an individual the different phases of this research are being conducted by various members of the Staff.

Such an investigation is a fine example of the organization of the Biochemical Research Foundation in its attack upon the problems of disease and of therapeutic aids.

The substance discovered by Dr. Hoogerheide to have bacteriostatic and germicidal qualities was naturally obtained at first in crude form. It was passed to the bacteriologists and cytologists to determine its qualities and powers, to the microchemists for analyses, identification and the determination of probable composition, to the organic chemists for fractionation, to the spectroscopists for characterization and for determination of spectrographic differences between the various fractions obtained by the chemists, to the cytologists for toxicity and other experiments on animals, to the microscopists for record of crystalline structure of various fractions, to the surgeons for study of its external effects upon badly infected wounds, to the physical chemists for the measurement of physical constants and further study as to its structure.

So the whole gamut is run, and, as the production of new fractions continues, these again require the same procedure and progress of study.

As Dr. Hoogerheide has several substances which have bactericidal powers, some of which have different qualities, each of these must be studied according to this group plan in order to find which is the best, and, if possible, extract from the most eligible, a final refined crystalline product with the best and highest character. After this there remains the most difficult part, the laboratory synthesis of an identical chemical compound having the qualities of the biologically-obtained fraction.

A brief resumé of the current work in this coöperative investigation follows.

Isolation of Bactericidal Agents from Soil Bacilli: The species which produced the bactericidal agent previously reported (*Journal of Bacteriology*, in press, JOURNAL OF THE FRANKLIN INSTITUTE, **229**: 677, 1940) appears to be widely distributed in soil and was isolated from many soil samples taken at random. It was further found that this production of bactericidal substance is by no means restricted to this particular species or to an apparently closely related species which was recently isolated by Dubos after pre-treatment of soil, for a two-year period, with Gram-positive bacteria. Cultures of the most common spore-formers, such as *Bac. subtilis*, *Bac. megatherium*, *Bac. mesentericus*, *Bac. cereus*, excrete similar bactericidal products during growth in broth cultures. No adaptation or "training" of strains of these species is necessary since it was possible to use strains which for years had been in "The American Type Culture Collection." Isolation of crude active material from cultures of these species was accomplished in the same way as described for the soil bacillus; however, usually a smaller yield was obtained. Whether or not the agents obtained from these species are the same as those from the isolated soil bacillus cannot be stated at this time, but will be reported later. Large scale preparation from cultures of these and other species is being carried out in this laboratory.

It has been found that the greyish, highly active, powdery substance, obtained from the soil bacillus isolated in this laboratory is not a chemical entity. One active component has been isolated from the crude material in crystalline form.

Isolation of a Crystalline Component: The crude product

was first dissolved in hot 95 per cent. alcohol and partially decolorized with Darco-charcoal. After evaporation of the solvent, the residue was extracted with acetone-ether (50–50 mixture by volume). That portion which remained insoluble in this solvent was retained for further investigation (Fraction I). The acetone-ether extract was evaporated to dryness and redissolved in a small volume of 95 per cent. alcohol; fifteen volumes of ether were then added to this solution. The clear, almost colorless solution was separated from a precipitate which formed and was evaporated to dryness. The residue was extracted with dry ether and recrystallized twice from absolute acetone (Fraction II).

Fraction I was obtained as a slightly colored amorphous solid, $[\alpha]_D = -94°$. Fraction II crystallized from hot absolute acetone as colorless needles or lens-shaped platelets.

Analysis of the Crystalline Component (Fraction II): Qualitative organic microanalysis showed the presence of carbon, hydrogen, nitrogen; if present, sulfur, phosphorus, and halogens were lower than 0.1 per cent.

Quantitative microelementary analysis by standard methods indicated that the substance was hygroscopic, taking up about 2 per cent. moisture on standing, the exact value depending on the atmospheric conditions. The substance could be dried without loss of bactericidal activity at 100° C. and 3 mm. Hg to constant weight in 6 hours, using a 20 mg. sample in the charging tube with ground cap. Carbon—62.7 per cent., 62.7 per cent.; hydrogen—7.59 per cent., 7.65 per cent.; nitrogen by the Dumas method—14.8 per cent., 14.9 per cent., 14.9 per cent.; ash—none. The micro melting point of the crystals (227 to 228° C.) determined on the Kofler hot stage was slightly lower than the one in the capillary tube (228–232° C.). Molecular weight determination by the cryoscopic method did not give acceptable values with camphene, cyclopentadecanon, and retene as solvents; in camphor the results differed more than usual, the most reliable values being 1340, 1410 and 1622. A calculation of the empirical formula has not been attempted.

Physical Properties of the Crystalline Component: The crystals as obtained from acetone were very brittle; therefore, they had to be recrystallized on the microscope slide. Due to

quick evaporation of excess solvent, the lens-shaped crystals were covered with a layer of amorphous material, as shown in Fig. 1. The crystals shown in Fig. 2 were photographed in a

FIG. 1.

Fraction II. Magnification 262 ×, recrystallized on slide.

FIG. 2.

Fraction II. Magnification 252 ×, crystals suspended in acetone in capillary.

thin-walled glass capillary, in which the recrystallization took place; suspended in acetone, lens-shaped platelets and colorless needles were observed. The crystal form seemed to be easily influenced by the presence of small amounts of impurities.

The purified crystals were examined * in a preliminary way for their optical crystallographic properties, the crystal size being, however, too small to permit ready quantitative determinations of constants. Using mixtures of Nujol-α monobromonaphthalene as immersion liquids, refractive indices were found to be $\alpha' = 1.545 \pm 0.003$ and $\gamma' = 1.570$ for a wave-length of 5461Å at about 25°. Although these may not represent the principal indices, they refer to a definite and reproducible crystal orientation. The crystals examined were small anisotropic plates of irregular outline, mostly in random aggregates. They displayed medium birefringence and low first order colors. The interference figures were quite faint, the crystals apparently being biaxial. Because of the small size of the crystal fragments, the optic sign was indeterminate.

The specific rotation of the crystalline component in an earlier stage of purification was found to be slightly positive; however, that of the final crystalline product has not been determined as yet.

The absorption curve, in the ultraviolet region, of a solution (0.1 per cent. in 95 per cent. ethyl alcohol) of the crystalline fraction together with that of a solution (0.05 per cent. in water) of tryptophane for comparison is shown in Fig. 3. The wave-lengths of the maxima and minimum and the extinction coefficient of the principal maximum for a 0.1 per cent. solution are:

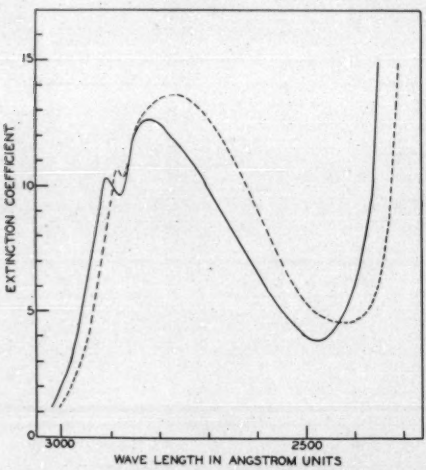
Substance.	Principal Maximum.	Secondary Maximum.	Minimum.	Extinction Coefficient at Principal Maximum.
Crystalline component (Fraction II).....	2815 A.U.	2910 A.U.	2475 A.U.	12.6
Tryptophane.....	2770 A.U.	2885 A.U.	2425 A.U.	27.3

It can readily be seen that in general form the curves are

* We are much indebted to Dr. W. M. D. Bryant of the Ammonia Department of E. I. du Pont de Nemours and Company for these observations.

similar. Quantitatively, however, they differ, for the absorption of the tryptophane is slightly more than twice that of the crystalline fraction. If the absorption of the crystalline

FIG. 3.



Absorption spectra. ——— Crystalline germicidal fraction (0.1 per cent. in 95 per cent. alcohol); - - - - - Tryptophane (0.05 per cent. in water).

product is assumed to be due to its tryptophane content about 50 per cent. tryptophane could be expected upon hydrolysis. In that case the remaining 50 per cent. of the molecule, while not adding directly to the absorption, would probably cause a shift in the bands toward the red end of the spectrum, which, indeed, is observed when comparison is made with the tryptophane curve.

These curves were determined with Hilger notched echelon cells in connection with a medium-sized Bausch and Lomb quartz spectrograph. Four sector settings were used for each determination which gave a total of 40 different values for the extinction coefficient between 1.2 and 15.

Chemical Properties of the Crystalline Component: The

crystalline fraction is readily soluble in ethanol, methanol, acetone, ethyl acetate, dioxane, chloroform, pyridine, glacial acetic acid, but is insoluble in ether, petroleum ether and benzene. A positive test was obtained with an alcoholic solution of the crystalline product for most of the common protein reactions. The biuret reaction was strongly positive. By using a casein solution of the same concentration for comparison it was found that the lower limit giving a positive test was the same for both compounds. The xanthoproteic reaction, too, was strongly positive. The lowest limit giving a positive xanthoproteic reaction was about 20 times as low for the crystalline fraction as for casein. Since the xanthoproteic reaction depends upon the aromatic nucleus of the protein molecule this indicates a high content of tryptophane or tyrosine. The Millon reaction was also positive, but the color obtained was yellow compared with reddish for a similar concentration of casein, indicating tryptophane in the molecule rather than tyrosine. Another indication of the presence of a high tryptophane content was an intense reaction of Voisenet, a reaction specific for tryptophane. In order to obtain a similar intense Voisenet reaction for casein, a concentration 50 times higher had to be used. The "ninhydrin" reaction, as well as the Molisch test, was negative. As may be seen from these results and the probable magnitude of the molecular weight, the crystalline fraction appears to be a polypeptide, with tryptophane as a major constituent.

The results suggest a similarity between the crystalline Fraction II and "gramicidin," a bactericidal crystalline fraction obtained by Hotchkiss and Dubos from crude material also isolated from a soil bacillus culture. There are however certain differences which at the present time do not justify complete identity of both. For instance, Dubos' crude material, containing gramicidin, "does not give any of the common protein tests (biuret, xanthoproteic, Millon, Hopkins-Cole, Sakaguchi) even when used in high concentrations." Furthermore the nitrogen content of crystalline Fraction II was found to be 14.9 whereas gramicidin contains 13.9 per cent. It is possible that this difference in nitrogen content is due to the method used for nitrogen analysis.

Biological Activity—Inhibition of Encapsulation: The crys-

talline fraction was found to have but slight effect upon the encapsulation of Friedländer's bacterium. An amount of approximately 40 gamma per cc. culture medium was necessary to obtain an appreciable inhibition of encapsulation, about 8 times as much as the amount of the crude material required. In accordance with this finding, the potency of the crude material after removal of the crystalline fraction increases markedly in regard to capsule-inhibitory power.

Inhibition of Growth of Gram-positive Microörganisms: The crystalline fraction is highly bactericidal. When it is added to culture medium (4 per cent. neopeptone-1 per cent. glucose solution) an amount as small as 0.00001 mgr. (0.01 gamma) per cc. broth showed a slight but definite inhibition of growth of *Gaffkya tetragena*. This minimum concentration for growth inhibition differs very much with the organisms studied. For instance, for *Staphylococcus aureus*, in the same medium and under identical conditions, the lower limit is approximately 0.5 gamma per cc. culture medium. Other Gram-positive organisms studied have intermediate lower limits. In order to prevent growth of Gram-positive microorganisms over a period of 24 hours or longer, much higher concentrations of the crystalline fractions are required, e.g., to prevent the growth of *Gaffkya tetragena* at least 0.6 gamma per cc. broth had to be added. In the case of *Staphylococcus aureus*, this amount is as high as 20 gamma per cc. In general, the crystalline fraction seems less active than the crude material and it seems therefore that the residue contains other more potent fractions.

Phenol Coefficient Tests: To test the actual killing power of the principle under prescribed conditions of time, temperature and concentration, phenol coefficient tests were done with several different organisms. These preliminary tests showed that the active principle killed the test organisms under the conditions used for disinfectant testing in quite high dilutions. Because the agent is not expected to be used primarily as a disinfectant, the phenol coefficient is probably less indicative of its true value than are inhibition tests. When tested in the presence of serum, the effectiveness was greatly reduced, as is generally the case with germicides. The preliminary tests with the crystalline fraction obtained from the crude product

indicate that it is less effective as a bactericide than the original crude material.

Toxicity: The crude material was tested for toxicity in mice, rats, guinea pigs and rabbits. The toxic intraperitoneal or subcutaneous dose was much higher than the toxic intravenous dose. Administered orally or rectally the crude material was comparatively non-toxic. Daily doses of 20 gamma, injected intravenously in 5 per cent. glucose solution, were not tolerated by mice, although these animals withstood 300 gamma administered subcutaneously, in one dose. The intraperitoneal toxic dose was about the same as the subcutaneous toxic dose. Mice withstood a single dose of 4 milligrams, given orally, without showing any effects.

Administered intravenously, a dose of 0.5 milligram of the crude material was fatal to approximately 50 per cent. of the rats to which it was administered. Rats would not withstand daily intravenous injections of 40 gamma of this material. When the same dose was administered intramuscularly, however, the animals were not affected. Rats withstood a dose of 2 milligrams, administered rectally.

The toxic dose for guinea pigs, administered intraperitoneally, was about 2 milligrams, although the animals tolerated nineteen daily injections of 200 gammas, intramuscularly. There was some myositis at the site of injection.

Rabbits withstood intravenous injections of 2 milligrams of this crude material, although a dose of 4 milligrams was fatal. Rabbits have tolerated daily intramuscular injections of 200 gamma for thirteen days out of eighteen with no apparent ill effects.

Daily injections in rats, intravenously, intraperitoneally, subcutaneously, or intramuscularly, cause a slight anemia in 25 days, the average blood count dropping from 5,735,000 to 4,640,000. During the same time there was a rise in total number of leucocytes in the circulating blood. The crude material also caused hemolysis *in vitro*. Two gamma were sufficient to cause hemolysis of the red corpuscles in 1 cc. of freshly drawn and oxalated human blood within two hours.

The purified crystalline material was less toxic to mice than the crude product. The crystalline material, injected intravenously in 5 per cent. glucose, did not kill any mice

receiving 100 gamma or less; 75 per cent. of the animals receiving 150 gamma died within 3 days. This pure material lacked the powerful hemolytic properties possessed by the crude product, since it did not cause any appreciable hemolysis in a concentration of 500 gamma per cc.

Protective effect in vivo: Both the crude material and the crystalline component isolated from it protected mice from infection with Type I pneumococcus or *B. anthracis* when the protective material was mixed with the culture immediately prior to the intraperitoneal injection of the mixture. When, however, the infecting organisms (10,000 to 1,000,000 lethal doses) were injected intraperitoneally and the protective material was injected intravenously after a lapse of two hours, little protection was observed. Similar results were obtained when the protective material was injected subcutaneously or intramuscularly. When it was injected at the same site as the infecting organisms, i.e., intraperitoneally, protection was shown. It appeared that the site of injection of the protective material rather than the time that elapsed between the injection of the organisms and the injection of the substance was the governing factor.

For example, 24 mice were injected intraperitoneally with 0.1 cc. of a 5-hour culture of Type I pneumococcus. Immediately following the injection of the infecting organisms, 25 gamma of the crystalline material in 0.05 cc. of a suspension in distilled water were injected subcutaneously in six mice. Six mice were injected intraperitoneally with the same amount of material, and the other 12 mice served as controls. The control mice all died within 24 hours; 4 of the 6 mice injected subcutaneously died within 48 hours; while the mice injected intraperitoneally died between 72 and 96 hours. Similar results were obtained when using *B. anthracis* as the infecting organism and either the crude material or the crystalline component as the protective agent.

The protective effect of a single injection of the crystalline material does not appear to last for more than 3 days on mice infected with Type I pneumococcus or *Bacillus anthracis*.

Clinical Application of the Bactericidal Agent: The originally isolated material has been used by Dr. V. W. Murray Wright in treating surgical conditions. The conditions in the 15

human patients were all external lesions and his experience in these cases indicates that the material is very valuable and safe in treating superficial external infections. Whether or not later investigations will show that the material can be used in combatting systemic or internal infections of the human body remains to be seen.

The clinical conditions in which the material has been used in the form of wet dressings or packs saturated with a colloidal suspension of the crude material in varying strengths from 20 to 100 gamma per cc. are as follows: (1) Large, badly infected sloughing abdominal wound (Staphylococci and Streptococci), (2–3) two deep, large abscesses of the breast (Staphylococci and Streptococci), (4) third degree burn of finger, (5–6) two cases of acute rhinitis and maxillary sinusitis, one with acute cervical adenitis (Staphylococci and Streptococci), (7) Streptococcus infection of toe, (8) infected felon of finger, (9) large, severe, sloughing infection of arm, (10) large infected carcinoma of foot, (11) infected fibro-sarcoma of thigh, (12) infected carcinoma of lung with external sinus, (13) Staphylococci palmar infection of hand, (14–15) infected draining abdominal incisions following operations for gangrenous appendicitis.

All of the above lesions responded remarkably to treatment within 24–48 hours. In addition to a rapid combatting of the infection, the preparation appears to have another effect, namely, that of causing the wounds to heal quickly. Our brief experience indicates that the originally isolated material in solution is safe to use on external lesions, that it quickly arrests infections caused by Gram-positive organisms, and that it stimulates wound healing.

BOOK REVIEWS.

MINERAL METABOLISM, by Alfred T. Shohl. 384 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1939. Price $5.00.

At first glance the functions of minerals in the human body are obscure. They yield no energy and may undergo no change in chemical combination. It would appear then, that minerals are needed only in growth, but such is not the case. The adult requires them as much as the infant. Probably every function of cellular activity is dependent upon the mineral elements. This revelation is a comparatively recent one. Various other findings on the composition and requirements of the body have emphasized the importance of minerals and there resulted a great mass of conflicting data, more or less bearing on mineral metabolism. The author of this monograph states that it is an attempt to bring order out of apparent chaos with the hope that it will make available to the non-specialist the trends in the field.

After a brief introductory chapter the book opens with a summary of the composition of the body as a whole, of the organs, and of the body fluids, in regard to water and minerals. It includes a description of both the qualitative and quantitative interrelationships of the electropositive and electronegative elements and radicals. A detail of secretions is then given, showing their collective effect on the body fluid. At this point a summary is made of the activities of the individual elements, total base, the alkaline minerals sodium and potassium in relation to each other and to chloride, and ammonium and bicarbonate.

For the subject matter in the book, the author has chosen an arrangement, in the main, of covering the several elements under each of the many physiological functions although there is a correlation of functions from the point of view of minerals. The construction of the book therefore is such that it recognizes both methods of presentation. The latter chapters cover calcium and magnesium, phosphorus, sulfur, iron, iodine, traces, water metabolism, anion-cation relationships, and mineral intakes, balances and requirements.

The book is an explanation of the relations of the minerals to life processes. Each of the minerals is shown to have specific and varied functions. It gives the relation of minerals to the kinds and amounts of food usually eaten and the adequacy of the average consumption is evaluated. It is a remarkable exposition of admirable ability in the assimilation of a great mass of data, the abstraction and arrangement of this data, and the effective presentation of it in a logical and readable manner. The book is a contribution to the literature which will be of much assistance to the search for more knowledge.

R. H. OPPERMANN.

STATISTICAL METHOD FROM THE VIEWPOINT OF QUALITY CONTROL, by Walter A. Shewhart. 155 pages, illustrations, 17 × 25 cms. Washington, The Graduate School, Department of Agriculture, 1939.

The application of statistical methods in mass production makes possible the most efficient use of raw materials and manufacturing processes, effects economies in production, and makes possible the highest economic standards of quality for the

manufactured goods used by all of us. So states one of the first pages of this book. Because of the experience gained in industry the author was invited to deliver four lectures before the Graduate School of the Department of Agriculture with the thought that much was to be gained by correlating the development of statistical methods of research as applied in agriculture with the statistical methods of control in industry. The book contains the four lectures edited for publication.

Central to the theme of the four lectures is the concept of the act of control, which consists of the three components (*a*) the act of specifying the end to be attained, (*b*) the act of striving to attain the end specified, and (*c*) the act of judging whether the end has been attained. In mass production these are called specification, production and inspection. In scientific method they may be likened to hypothesis, experiment, and test of hypothesis.

Chapter I shows that the nature of the problem of judging whether a state of statistical control exists is essentially one of testing the hypothesis that assignable causes have been eliminated. Chapter II takes up the practical problem of establishing tolerance limits that will make possible the most efficient use of raw materials and pieceparts. The problem of providing an efficient running quality report in mass production is discussed in chapter III. The fourth chapter takes up the simplest type of problem of specifying in an operationally verifiable way a state of statistical control of a single quality characteristic.

The treatment refers to applications on measurements and practical situations which go far in the way of assistance to clarity. It can be recommended to those interested in this field of endeavor.

R. H. OPPERMANN.

M. K. S. UNITS AND DIMENSIONS AND A PROPOSED M. K. O. S. SYSTEM, by G. E. M. Jauncey and A. S. Langsdorf. 62 pages, illustrations, 15 × 22 cms. New York, The Macmillan Company, 1940. Price $1.00.

This is a description of the properties of the new meter-kilogram-second system of basic units adopted by the International Electrotechnical Commission in 1935 to become effective in 1940. It contains data on methods for changing from one set of basic units to another, reasons for the adoption of the ohm as the fourth basic unit, a description of a proposed M. K. O. S. system of basic units, and a discussion on the difference between magnetic flux density and magnetic field strength. The use of the system involves no change in the practical electrical units, but its magnetic units differ from those commonly used. It is a clear presentation and should be of value to those whose activities may be affected by the changes which are still a possibility. The decision made by the official organization for the adoption of the units could not be carried out on January 1, 1940 because agreement had not been reached on exact values. Further comparisons of standards between the various national laboratories will be necessary before a new date can be fixed. Such work cannot be carried on during the war.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

An Introduction to Astronomy, by Robert H. Baker. Second Edition, 315 pages, plates, illustrations, 16 × 24 cms. New York, D. Van Nostrand Company, Inc. Price $3.00.

Physical Constants of Hydrocarbons, Vol. II, Cyclanes, Cyclenes, Cyclynes, and other Alicyclic Hydrocarbons, by Gustav Egloff. 608 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1940. Price $12.00.

Printing Inks, Their Chemistry and Technology, by Carleton Ellis. 560 pages, illustrations, 16 × 24 cms. New York, Reinhold Publishing Corporation, 1940. Price $7.00.

Living Light, by E. Newton Harvey. 328 pages, illustrations, plates, 16 × 24 cms. Princeton University Press, 1940. Price $4.00.

Electrical Timekeeping, by F. Hope-Jones. 275 pages, illustrations, 15 × 23 cms. London, N. A. G. Press Ltd. Price 10 s.

Laboratory Manual of Physics, by Clinton Maury Kilby. Second Edition, 146 pages, illustrations, 14 × 22 cms. New York, D. Van Nostrand Company, Inc. Price $1.75.

Light and Colour in the Open Air, by M. Minnaert. 362 pages, plates, illustrations, 15 × 23 cms. London, G. Bell and Sons, Ltd., 1940 Price 15 s.

Why Smash Atoms, by Arthur K. Solomon. 174 pages, plates, illustrations, 16 × 24 cms. Cambridge, Harvard University Press, 1940. Price $2.50.

Photographic Facts and Formulas, by E. J. Wall. 384 pages, illustrations, 16 × 24 cms. Boston, American Photographic Publishing Co., 1940. Price $2.50.

Classical and Modern Physics, by Harvey E. White. 712 pages, illustrations, plates, 16 × 24 cms. New York, D. Van Nostrand Company, Inc., 1940. Price $3.75.

Cosmo-Retardation, by I. Ziporyn. 251 pages, illustrations, 14 × 20 cms. Detroit, Dexter Publishing Co.

Canada, Department of Mines and Resources. Mines and Geology Branch. Tests on The Liquefaction of Canadian Coals by Hydrogenation, by T. E. Warren and K. W. Bowles. 107 pages, plates, illustrations. Comparative Tests of Various Fuels when Burned in a Domestic Hot-Water Boiler, 1935 to 1938, by C. E. Baltzer and E. S. Malloch. 23 pages, plates, illustrations. 2 pamphlets, 17 × 25 cms. Ottawa, King's Printer, 1940. Price 25 cents each.

National Advisory Committee for Aeronautics. Technical Notes: No. 757, A Study of Unsymmetrical-Loading Conditions, by Henry A. Pearson. 46 pages, illustrations. No. 758, Measurements and Analysis of the Motion of a Canard Airplane Model in Gusts, by Philip Donely, Harold B. Pierce, and Philip W. Pepoon. 29 pages, illustrations. No. 760, A Full-Scale Investigation of the Effect of Several Factors on the Shimmy of Castering Wheels, by Walter B. Howard, Jr. 22 pages, illustrations. 3 pamphlets, 20 × 26 cms. Washington, Committee, 1940.

Bell Telephone System, Monographs: B-1211, Molecular Rotation in Non-Aromatic Crystals, by Addison H. White and W. S. Bishop. 16 pages, illustrations. B-1213, The Porous Structure of Paper in Relation to Drying and Impregnation, by D. A. McLean and G. T. Kohman. 12 pages, illustrations. B-1214, Ash-Forming Constituents of Insulating Papers, by D. A. McLean. 12 pages, illustrations. B-1215, Spectrochemical Analysis, by E. K. Jaycox and A. E. Ruehle. 12 pages, illustrations. B-1216, Spectrophotometry and Colorimetry, by A. E. Ruehle and E. K. Jaycox. 6 pages, illustrations. 5 pamphlets, 15 × 23 cms. New York, Bell Laboratories, 1940.

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